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OFFICE OF EXPERIMENT STATIONS,
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Irrigation Investigations, Elwood Mead, Expert in Charge.

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THE RESERVOIR SYSTEM OF THE CACHE LA POUDRE VALLEY.

BY

E. S. NETTLETON.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1901.

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POTATO FIELD NEAR GREELEY, COLO.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
A. C. TRUE, Director.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., December 15, 1900.

Sir: I have the honor to transmit for publication as Bulletin No. 92 of this Office a report on the reservoir system of the Cache la Poudre Valley, Colorado, which has been prepared under the supervision of Elwood Mead, expert in charge of irrigation investigations, by E. S. Nettleton, formerly State engineer of Colorado, now agent and expert in irrigation investigations of this Department.

The benefits to be derived from the construction of reservoirs for the storage of water for irrigation are strikingly illustrated in the case of the Cache la Poudre Valley. In this valley a series of reservoirs has been constructed by local and individual enterprise, which, in connection with a system of rotation in the use of water, has resulted in doubling the area capable of being irrigated by the canals alone and in securing more thorough and effective irrigation than is usual without the aid of storage reservoirs. This account of the experience of the Cache la Poudre Valley in the construction and use of storage reservoirs has been prepared and is recommended for publication in the belief that it will prove valuable to many other localities, not only in Colorado, but in other arid States.

Very respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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THE RESERVOIR SYSTEM OF THE CACHE LA POUDRE VALLEY.

INTRODUCTION.

The average flow of the Cache la Poudre River for the month of July for fifteen years has been 840 cubic feet per second. The duty of water assumed in water-right contracts in this section is 80 acres to 1.44 cubic feet per second, or 55 acres per cubic foot per second. On this basis the average flow for July will irrigate 46,200 acres. The investigations of the duty of water made last year under the direction of the Office of Experiment Stations show that in the localities having the same general conditions as this valley the average depth of water applied to the land irrigated is about 3.25 feet.[1] That is, the water entering the head gates of the canals where measurements were made would cover the area irrigated under these canals to that depth providing it all reached the land. Assuming that the length of the irrigation season in the Cache la Poudre Valley is four months, and that the average flow of the river for July is the average for the four months, the natural flow of the stream would cover to that depth 62,945 acres. But the area actually irrigated by canals from this stream is at least 140,000 acres.[2] The profitable cultivation of this area is made possible largely by the system of reservoirs and the exchange of water which has been developed in this valley. Ten years only have been required to build up the most complete system of storage in the United States. This has not been accomplished by a large expenditure of money, nor because of unusually favorable locations for reservoirs, nor was it wholly by accident that the people of this valley took up this line of irrigation development—conditions forced

[1] U. S. Dept. Agr., Office of Experiment Stations Bul. 86.

[2] Estimates of the area irrigated in the Cache la Poudre Valley vary within wide limits. This is largely due to the two methods used in stating the area of land irrigated. In experiments made on a small scale the exact area watered is given. In considering large areas all the land under ditch is apt to be classed as irrigated. A farm of 160 acres will be classed as under cultivation and the entire area will be reported as irrigated, but in reality not more than 80 acres may be irrigated. Such areas as are included in public highways, private roads, or occupied by fences and buildings, should not be considered as irrigated lands. For this reason the area irrigated by the canals from the Cache la Poudre is in this bulletin estimated at 140,000 acres, considerably less than the usual estimates.

them into it. They did not wait for the General Government or the State to build reservoirs for them, nor did they wait for the people of some other locality to demonstrate their practicability and financial success. While this system is by no means completed, the owners have already reaped much larger rewards for their labors than they expected, reaching into the millions of dollars.

Although the necessity for storage reservoirs and their utility and benefits are generally recognized, but few people outside of northern Colorado are aware of what has been accomplished in that locality by the utilization of small things or of the ingenuity displayed in making the most of them. There are other localities, not only in Colorado, but in nearly every one of the arid States, where the work of these people can be followed with beneficial results.

The object of this bulletin is to bring this work before communities similarly located to the Cache la Poudre Valley, in order that they may obtain the benefit of the experience gained here, rather than work out the same problems for themselves, certainly with loss of time and perhaps of money.

THE CACHE LA POUDRE RIVER AND VALLEY.

The drainage basin of the Cache la Poudre River lies in the north central part of Colorado and on the eastern slope of the Rocky Mountains, or, more properly, on the east side of the Laramie and Medicine Bow ranges, which are spurs turning off to the north from the continental divide at a point about 25 miles northwest from Longs Peak. The summit of the ranges above named forms the western boundary of this basin; the divide between the Cache la Poudre River and the Big Thompson, the next stream south, forms its southern boundary; and the northern boundary is formed by the high plateau of southern Wyoming.

This basin is about equally divided between mountains and plains. The area of the mountainous part is approximately 1,050 square miles, 100 square miles of this being in Wyoming. The area outside the mountains is about 850 square miles.

The elevation of the plains portion of the basin is from 4,649 feet at Greeley, near the mouth of the river, to something over 6,000 feet along the southern line of Wyoming, and 5,200 feet where the river leaves the mountains and enters the plains. The elevation of the mountainous portion ranges from 5,500 to 13,000 feet, the latter being about the altitude of the summits of a few peaks in the ranges to the west, and refers to only a small portion of the drainage area.

From timber line, or an elevation of about 11,500 feet, down to about 7,000 feet is the forest area, which was at one time very generally covered with a dense growth of several species of pines. This

growth was especially heavy in the gulches and other favorable localities. Since the advent of railroads to the country near by, and sawmills on the spot, and hordes of prospectors, tourists, and others with a spark of fire in their pockets, these forests have been rapidly disappearing.

The head of the main river is the outlet of Chambers Lake, which formerly covered an area of about 54 acres. This lake is fed by two or three little mountain brooks, coming in from the south and west, forming a beautiful little lake at an elevation of about 9,000 feet. From the lake to the mouth of the canyon where the river reaches the plains is about 35 miles in an air line, and probably 60 to 70 miles following the meanderings of the stream. In its course through the mountains the river is reenforced by the South and North forks and several small tributaries. The general course of the river after it leaves the mountains is southeasterly until it joins the South Platte River, about 3 miles below Greeley and some 35 miles from the mouth of the canyon. From the canyon to its mouth the river receives no tributaries of any size.

As shown by the map (Pl. XI, p. 38) the principal part of the irrigable land in the valley lies on the north side of the river, except at the upper end near the foothills, where there is quite a wide belt of level country on the south side. Below this the river runs close to a range of high, rough-faced bluffs, leaving only a narrow strip of first bottom lands. On the north side the first bottoms are about equal to those on the south, but instead of being backed by high bluffs there is a gentle rise of a few feet to the "first bench" lands, which gradually rise toward the north at the rate of about 25 feet per mile to near the Wyoming-Colorado line. The area susceptible of irrigation from this river, then, is practically unlimited. So far as the configuration of the country is concerned, canals could be run high up on this bench and extended indefinitely down the South Platte Valley. The surface of nearly the whole valley is admirably adapted to irrigation, although there are some parts where it is a little too rolling.

The water supply of the river comes almost entirely from the melting of the snows in the mountainous part of this basin, so that the valley outside the mountains and foothills is not considered as available gathering ground except as it collects the unreliable storm waters of an arid country. The volume of water carried by the stream varies from year to year with the amount of snowfall in the winter, from month to month with the temperature, and even from hour to hour. The flood period is in the early summer, usually from June 1 to June 15, while the daily high tide reaches the mouth of the canyon usually in the early morning of the day following the melting of the snow in the mountains, and the flow at this time is sometimes double what it is later in the same day.

At the lower end of the canyon a measuring device was erected in 1884, and has been maintained since that time (Pl. II).[1] A record is kept, showing the discharge of the river during the irrigating season. The following table shows the average flow for the months from March to October for the entire period from 1884 to 1898, and the percentage of the total flow for the season, which occurs each month:

Average monthly flow of the Cache la Poudre River, for the years 1884 to 1898, inclusive.

Month.	Cubic feet per second.	Per cent.	Month.	Cubic feet per second.	Per cent.
March	69.81	1.46	August	339.36	7.07
April	205.53	4.28	September	174.27	3.63
May	1,141.13	23.78	October	120.53	2.51
June	1,908.27	39.76			
July	840.32	17.51			100.00

The flow in any single year varies much more than the average shown in the table. The record shows a discharge of over 5,000 cubic feet per second on several days in June, 1884, and as low as 862 cubic feet per second in July of the same year. Some snow often remains on the mountains through the summer and furnishes a small supply of water until cold weather sets in. This flow is usually augmented in the middle of the summer by rains which are variable but constant enough to make a fairly well-defined period of summer rains.

SETTLEMENT AND DEVELOPMENT.

The real and rapid progress in the agricultural development of the Cache la Poudre Valley began with the building of the Denver Pacific Railroad and the coming of the Union Colony to the lower end of the valley at Greeley. Prior to this there were a few settlers in the valley, scattered along its entire length, and two small settlements near the foothills—one at Laporte, the other at Fort Collins. Laporte is just below the mouth of the canyon, and was the watering and feeding

[1] Pl. II is a view of the gaging station in the canyon of the Cache la Poudre River, about 1½ miles above the mouth of the canyon. The river at this point is very narrow, the distance between the stone walls shown in the view being 100.8 feet. Originally the bottom of the river was floored over with 4-inch plank 20 feet long, laid up and down the stream, making, with the vertical stone walls, a rectangular section through which all the water of the river must pass. The fall of the river at this point is about 30 feet per mile, and the velocity varies with the depth of water flowing in the river. The area of the cross section and the velocity of the water at various depths having been previously determined, to obtain the discharge at any time it is only necessary to know the depth of water flowing in the stream. A continuous record of the depth of water in the river is kept by an automatic register in the small house at the right of the view. This gaging station was first installed in 1883. It was destroyed in June, 1891, by high water, caused by the breaking of the Chambers Lake dam, but was rebuilt as soon as the flood subsided, and has been maintained in fair condition to the present time.

GAGING STATION ON CACHE LA POUDRE RIVER.

place for man and beast during the days of the overland emigration to California. Fort Collins is a few miles farther down the river, and was at that time a military post and supply depot used by the Government as a base from which protection against hostile Indians was given to the settlers and emigrants.

It was at Laporte that the first attempts were made to raise anything by irrigation in this valley. Vegetables were the first products. Later, small fruits and horse feed—native hay and oats—were raised. When the gold excitement reached Colorado the ranch business attracted more settlers. Their chief industry was raising native hay, which was sold at the mining camps for from $50 to $100 per ton. The more progressive farmers made small irrigating ditches and cultivated a few acres of vegetables, wheat, and other small grains, all of which brought fabulous prices in the mountain mining camps. Irrigation at this time was confined to the "first bottoms," for two reasons: The labor and expense of building ditches was small, and it was thought that the heavy, black alluvial soil of the river bottoms was by far richer and better than the light, sandy soil of the higher country.

The Union Colony came in 1870. The locating committee selected about 50,000 acres of land, lying on both sides of the river and extending from its mouth up the valley some 12 or 15 miles. Each alternate section was railway-grant land, the most of which the colony bought. The remaining sections, being public lands, were open to purchase and settlement under the various land laws then in force. In a very short time these public lands were all taken up by colonists, so that the colony had control of practically all the land in a strip 5 or 6 miles wide and 12 to 15 miles long, excepting a few ranches on the first bottom which were owned by earlier settlers. Some of the colonists tried to buy these, but they were held at such exorbitant prices that the newcomers were forced to locate higher up, on the sandy bench lands, where, in the opinion of the "old timers," they could not get water, and even if they could, nothing could be made to grow.

Most of the colony lands lie on the north side of the river. Above the first bottoms the soil is a reddish-brown sandy loam. The surface was generally covered with short buffalo and gamma grasses, with small pad cactus interspersed, the cactus predominating on the more sandy portions. The land on the south side of the river was covered by a canal called the Greeley No. 3, built in 1870. Those on the north side were covered by the Greeley No. 2 canal, built in 1871. (See Pl. XI, p. 38.) This was the first "high-line" canal in Colorado, built to cover land above the river bottom.

In the years 1871 and 1872 farming operations were commenced. Wheat was the principal crop raised, and it found a ready market at good prices. Oats were also a profitable crop. Under good farming,

which includes proper irrigating, the yields of wheat were large, ranging from 25 to 50 bushels per acre. Corn was tried but did not succeed, as the nights are too cold. Potatoes were planted, and succeeded well the first year or so, but afterwards failed for a number of years. Flax was experimented with. It grew well, but could not be rotted so as to get out the fiber. Clover did not do well. The result was that wheat and other cereals were the staple crops for the first decade of the development of the valley. All of these were planted about the same time of the year, and needed water at the same time—the early part of the summer. Weather conditions were such that often the whole valley needed to be irrigated during the same weeks. To do this was to overtax the carrying capacity of the canals for a short time, though there was usually plenty of water in the river at this season of the year. It was only a question of enlarging the canals to carry the water. This done, the farmer thought he would be forever free from any anxiety concerning scarcity of water. With these crops the irrigation season was very short, some years lasting from six weeks to two months.

During this decade the yield of the various small grains began to show signs of falling off from the effects of continuous cropping with the same grain. Rotation with one kind of grain following another did not prove to be of much benefit. Corn was tried, partly with the idea that it might improve the fertility of the soil, but mainly with the hope that cultivation during the growing season would destroy the weeds that were becoming a nuisance. The yield of this crop did not justify its continued cultivation, nor did it bring back nor add to the soil what the small grains seemed to need. Plowing under partially rotted straw for a fertilizer only put the land in bad condition for retaining moisture, and common barnyard manure was not to be had in sufficient quantities to be of much value. The fertilizing effects due to the use of silt-carrying water failed to keep up the land, as the waters of the Cache la Poudre were somewhat barren of this great source of wealth that in many localities had been known to keep lands in good condition generation after generation with the application of no other fertilizing agent. With prices of grain declining, and the yield of farm crops growing less, it was thought that the limit of the agricultural development of the valley had been reached.

Fortunately, about this time the possibility of successfully raising potatoes under irrigation was discovered, and the proper use of alfalfa was found out. Alfalfa was first planted in 1872, but it was thought at that time that land once planted to alfalfa must remain in that crop forever, as its roots were so large, extended so deep, and were so full of vitality that no plow could root them up and no form of cultivation could eradicate the plant. Notwithstanding all this, a few farmers concluded to try it and set apart small fields, which, after due delibera-

tion. they thought they could sacrifice. For some years no attempt was made to turn under any of this alfalfa, but eventually some one tried and found that it could be plowed under and that other crops following it made unheard-of growth. In the years 1883 to 1886 the practice became general. To-day about one-third of the entire cultivated area of the valley is devoted to growing alfalfa for forage and fertilizing purposes. Probably the introduction of no one agricultural product during the last half century has done more for the agriculturist in any section of the country than alfalfa has done for the farmer of the Cache la Poudre Valley. It enables him to put his land at once in fine tilth and great fertility, and at the same time raise a profitable crop.

As was said, potatoes were planted and did well the first year after the arrival of the colonists, and then failed for some years. However, a few farmers kept trying to raise them, and finally succeeded, and their culture has improved and spread until now the vicinity of Greeley is one of the most noted potato-growing regions in the United States. As the country has become settled and the holdings have become smaller, farming has become more intensive, and the ordinary field crops have in many places given way to orchards and gardens. Already onions and cabbages raised in this valley are finding good market outside the State, as do the Greeley potatoes, on account of their fine appearance and quality. Onion raising is a growing industry, and the onion bids fair to rival the celebrated Greeley potato. Onion culture requires more hand labor than potato raising, and for this reason probably will not develop so rapidly. This crop requires more or less late water, and is therefore dependent upon stored water for full development and assurance of regular annual crops.

ROTATION OF CROPS.

Land could not stand continuous cropping with grains, nor can it with other crops. Rotation is necessary. Alfalfa is the foundation of the system of rotation adopted, and hence may be said to be the basis of the agricultural prosperity of the valley. Twenty years' experience in its culture has demonstrated that it is an excellent and cheap fertilizer, freeing the ground from weeds and leaving it in good tilth, and at the same time producing profitable crops of forage. With proper rotation with alfafa as a base, land can be farmed indefinitely with no outlay for fertilizers and without summer fallowing. The object sought in rotation is to produce the greatest possible value and at the same time keep the land in good condition. Potatoes are the most valuable crop extensively raised in the lower end of the valley. Wheat is next, and alfalfa is probably next, in addition to its value as a fertilizer. The following plan of rotation was outlined by Mr. H. C.

Watson, of Greeley, and will be called the Watson system. A farm is assumed to be divided into four equal plats, and the table shows the crops to be raised for four years from the sod. A supply of early and late water is also assumed.

Watson system of crop rotation.

Year.	Plat 1.	Plat 2.	Plat 3.	Plat 4.
1	Oats	Wheat	Potatoes or corn	Potatoes or corn.
2	Oats; seed to alfalfa	Potatoes; plow deep	Wheat	Wheat.
3	Alfalfa	Wheat	Wheat; seed to alfalfa.	Potatoes; plow deep.
4	Turn under alfalfa and plant to potatoes.	Wheat; seed to alfalfa.	Alfalfa	Oats or wheat.

After the fourth year raise two crops of potatoes after alfalfa. Sow alfalfa in early spring, with either wheat or oats.

Ex-Governor B. H. Eaton gives the following rules for crop rotation:

Wheat may follow wheat once.

Wheat should never follow oats.

Oats had better follow wheat than oats.

Alfalfa should be seeded in the spring with wheat or oats, and should remain two years after the seeding year.

Potatoes should follow alfalfa, and may follow potatoes once.

The table below shows a rotation worked out on this plan, with the exception that alfalfa does not always remain on the ground two years after the planting:

Eaton system of crop rotation.

Year.	Plat 1.	Plat 2.	Plat 3.	Plat 4.
1	Wheat	Wheat	Oats	Oats or barley.
2	Wheat; seed to alfalfa.	Potatoes; plow deep.	Potatoes; plow deep.	Oats; seed to alfalfa.
3	Alfalfa	Wheat; seed to alfalfa.	Potatoes	Alfalfa.
4	Potatoes	Alfalfa	Wheat; seed to alfalfa.	Potatoes.
5	Potatoes	Potatoes	Alfalfa	Wheat.
6	Wheat; seed to alfalfa.	Potatoes	Alfalfa	Wheat; seed to alfalfa.
7	Alfalfa	Wheat; seed to alfalfa.	Potatoes	Alfalfa.

The particular plan of rotation which should be adopted by any farmer will depend largely upon the character of his water supply.

WATER REQUIREMENTS.

The gradual change from one-crop farming to a more and more intensive and diversified agriculture has been accompanied by as marked a change in the water requirements of the crops raised.

When the small grains were the only crops, the farmers were fairly at ease in regard to their water supply. When they needed the most water, they had the most. These crops were all planted in the early spring, and seldom required irrigating before the middle of May, and often not until the 1st of June. This was just the time of greatest supply. By the time the flood in the river began to subside, about the 1st of July, irrigation was finished, and the harvest and the season's work of the grain farmer were over. Usually much of the flood discharge and practically the whole flow of the river from this time until the next spring flowed past unused. This was really no loss to the one-crop farmer so long as he had a good supply during May and June, and enough for domestic use for the rest of the year.

The introduction of new field crops changed all this. Alfalfa requires water earlier in the spring than the grains, and a supply of late water will mature a third crop where usually but two can be raised without it, thus increasing the yield by nearly one-half. Potatoes are not planted until the period of high water in the river is nearly over, and they require water sometimes as late as the first of September, two months after the flood has subsided. Both orchards and small fruits require water throughout the summer, as do the cabbages and onions which are being so largely raised in the last few years. The area which can be planted to what we may call the late-water crops depends, of course, upon the quantity of water furnished by the river during the latter half of the summer, and the quantity which can be stored during the flood period and the winter for use during that time. As pointed out in the introduction, the natural flow of the stream supplies water for only a very small area during the late summer. In fact, the farmers found that they could not keep up their land and raise profitable crops with this flow of the stream. About 1890 they began to realize that something must be done to supply themselves with late water, and the construction of reservoirs was begun. So far the quantity of water which can be stored has been limited by the capacity of the improved reservoirs, and in almost every year water has run to waste during the flood period.

RESERVOIR SYSTEM.

SITES.

Nature has provided suitable sites for storing the surplus water at small expense. These sites are depressions in the surface of the country, with a depth of from 5 to 50 feet below the lowest points in their rims, and vary in area from a few acres to several sections. Nearly all of these basins have a small area of perfectly level land at their lowest points. The soil of the bottom of these depressions is generally an impervious, heavy clay, and often void of any vegetation, indicat-

ing that they once contained water much of the time. A few held water throughout the year. These were at the termini of ravines, or where the gathering ground was sufficiently large to collect more water than was lost by evaporation. Some of them once supplied water for the buffalo and antelope, and, later, for the herds of cattle that ranged over this section of the country. That great herds of buffalo frequently went to these places for water is evidenced by the great number of broad, deep-worn trails that radiated from them. The continued tramping of the bottom of the basins by countless animals for an unknown number of decades has made them so impervious that the water which accumulates in them remains until evaporated. Not only the bottoms are practically water-tight, but the sides are nearly so.

Many of these depressions which lie below or within areas that have been irrigated for a few years have been slowly filled by the waste water from the irrigation canals; others caught the seepage water of the surrounding country that naturally found its way toward the lowest exit. (See Pl. III.[1]) The fact that these basins were filled to overflowing by so small a supply of water proves that they do not absorb any great amount of water, even when not surrounded by irrigated land. Before the day of reservoirs it was considered a misfortune to lose the farming land within these basins by the gradual encroachment of the water, but now an acre of land is counted to be more valuable for reservoir purposes than for farming operations—in some instances from three to five times as valuable.

Most of the basins have depressions on one side of their perimeters. At these places the ground usually slopes more or less away from the basin, forming a natural place for the outlet. The length of the cutting or tunnel through the rim necessary to draw the water from the bottom of the basin depends on the slope of the ground both on the inner and outer sides of the rim. When the slopes are quite flat and the holding capacity of the basin at its bottom is small, the expense of making the outlet low enough to draw off all the water in the basin is

[1] Pl. III shows an alfalfa field, with the first and second cuttings in the stacks and the third crop on the ground just ready to be cut. This field lies adjoining the Larimer and Weld Reservoir, on the south side, and below the high-water line of the reservoir. This alfalfa field was not irrigated during the season. The only moisture it received was from the spring rains and that which came from the reservoir by percolation. The second and third crops had no rain to amount to anything, so the growth of these two crops was due to moisture supplied from the reservoir. We have no evidence that this reservoir when full lost any water either from percolation or evaporation, but statements are made that when the water is drawn off it slowly fills again from seepage that finds its way into it from the irrigated country above. It is therefore probable that reservoirs situated within an irrigated section where there is a gentle slope in one direction receive water from the upper country from incoming seepage and give it out by outgoing seepage to the lands lying below. This probably accounts for some reservoirs losing more or less water during the storage period, while others hold their own, and a few show a slight increase.

ALFALFA FIELD ON MARGIN OF RESERVOIR.

too great, and it is the usual practice to tap the basin above its lowest point, leaving more or less "dead water" in the reservoir, which can not be used for irrigation. This water is not wholly useless, as many of the reservoirs are stocked with fish, and the water remaining in the bottom affords protection to the fish during the time when the reservoir would otherwise be empty.

It is generally found that the holding capacity of these natural basins can be greatly increased by building an embankment on the saddle of the rim and extending it until it joins the higher ground surrounding the basin. There are several conditions which control the height to which these embankments may be built, such as have to do with their cost and safety. As a rule the cost of increasing the holding capacity of a basin by means of an embankment is so much less per acre-foot than the cost of making cuttings deep enough to take out a like amount of water that the tendency has been to increase the height of the embankment after the width of the base has been established, thus leaving the top too narrow for safety. The particular danger to guard against is the washing of the banks in case of high winds at a time when the reservoirs are full. Luckily, so far no accidents of any magnitude have occurred from this cause to any of the large reservoirs.

Another form of reservoir is made by building a dam or embankment across a ravine or small valley at some suitable place where the sides are comparatively close together. The cost of these per unit of holding capacity is several times greater than of those occupying the natural basins, and until the value of reservoir water is higher than it is at present in the Cache la Poudre Valley the cost of reservoirs of this style will outweigh their utility, except in a few places where the topographic conditions are very favorable.

There is still another form of reservoir which is not so much in use in the valley, because very few opportunities of this kind exist for creating an economical and practical storage of water. This form of reservoir contemplates damming the stream which furnishes the water supply. The streams within the country under consideration which can be relied on to fill reservoirs of any considerable size are those which have their sources in the elevated mountainous country. The fall of these streams is so great, and the valleys are so narrow, that a high dam is generally necessary to impound any great quantity of water. Then the dams must necessarily be expensive on account of the character and form of construction required, and when their holding capacity is considered, the cost per acre-foot precludes their creation at the present time.

No thorough or extended topographic surveys of the valley have been made, so that the number and size of the natural basins in the Cache la Poudre Valley yet unimproved can not be given, but some idea may be had of the large number when it is stated that for sites in this

valley alone 65 filings have been made in Larimer County and 47 in Weld County. Five of the largest reservoir systems in the valley are described in the following pages.

THE CACHE LA POUDRE RESERVOIR.

The Cache la Poudre Reservoir Company was organized and incorporated in 1892. The incorporators were farmers owning lands under the canal of the Cache la Poudre Irrigating Company, known as the Greeley No. 2 Canal. The charter of the canal company did not authorize the building and operating of reservoirs; hence the formation of the reservoir company. Although the two companies are distinct organizations, the business of the two is practically under the same management. Both are stock companies, and with few exceptions the holders of the canal company's stock are stockholders in the reservoir company. The capital stock of the reservoir company is $60,000, divided into 3,000 shares of $20 each. The articles of incorporation provide for subscription to this stock as follows:

> The subscription to said stock shall be limited to two classes of persons:
>
> First. Those owning, controlling, or in possession of lands under said reservoir or reservoirs capable of irrigation therefrom; and
>
> Second. Those owning, controlling, or in possession of lands under the canal of the said the Cache la Poudre Irrigating Company capable of irrigation therefrom and who have stock or water rights in said company.
>
> That those under the canal aforesaid shall be entitled to take stock in this company upon the ratio only of one share of stock herein to one share of stock in the said canal company, and that the said reservoir water when diverted into said canal shall be divided in the same ratio, and that an 80-acre water right in this company when diverted into said canal shall equal an 80-acre water right in said canal company, and be delivered and divided in said canal in the same ratio to those lawfully entitled thereto.

This stock is assessable whenever money is needed for any of the purposes authorized by the charter.

Eight shares of the stock represent one water right, each holder of eight shares being entitled to one three hundred and seventy-fifth of the water in the reservoir each season.

The object of the organization of this company was to construct a reservoir for an additional supply of water to lands under the No. 2 Canal and the Lake Canal when the flow of the river is too low to supply the water necessary for late crops, mostly potatoes and alfalfa. Immediately after its organization the company began the construction of its reservoir.

This reservoir is situated near the town of Timnath, and about 6 miles southeast of the city of Fort Collins. It is in a small valley, rather than in one of the natural depressions before described. It includes ground once occupied by the Lake Canal, which was relo-

cated and built around on the lower side of the reservoir at considerable expense. The reservoir embankment crosses the valley at a very favorable location. On the southwest side were several hundred feet of low ground, which required another embankment to raise the water to the desired height. The cost of these embankments and that of changing the location of the canal and protecting a long line of earthen embankments from washing, added very materially to the cost of the reservoir.

The height of the main embankment above the outlet is 37 feet. The outlet is at the lowest point crossed by the dam. The high-water line is 7 feet below the top of the dam. The embankment is about 20 feet wide on top, affording an excellent roadway. (See Pl. VII, fig. 1, p. 34.) The protection against washing of the embankment consists of a single row of piles driven into the bank a few feet back from the high-water line, which are planked up on the bank side and filled in behind with rock. The outlet gate is set on cement masonry and the conduit is constructed of Fort Collins flagging laid in hydraulic cement. (See Pl. VII, fig. 2, p. 34.)

The reservoir when filled to the depth of 30 feet covers an area of 520 acres and has an estimated capacity of 358,000,000 cubic feet, or 8,218.5 acre-feet. Each water right, representing one three hundred and seventy-fifth of the water in the reservoir, entitles its owner to 954,667 cubic feet, or 21.92 acre-feet, when the reservoir is filled to the height of 30 feet.

It is the usual practice to make the first division by supplying 800,000 cubic feet to each water right instead of 954,667 cubic feet. The object of dividing first on a smaller quantity is to make sure that there will be enough to serve all alike. If at the end of the first division there is water left, as there usually is, another pro rata division is made of the water remaining.

The table given below shows the capacity of the reservoir between various depths. Excepting in 1897, until the present year the amount of water drawn from the reservoir has been estimated as best could be done. In 1897 the company conceived the idea of attempting to measure the water drawn off. A graduated gage rod was placed in the reservoir convenient to the regulating or outlet gate and a weir was put in the outlet channel. The man in charge was required to note the gage-rod reading and the time of opening and changing the gate, and at the same time the height of water on the weir. From these notes are obtained the data for computing the amount of water drawn off from the reservoir, which is the holding capacity of the reservoir between the readings on the gage rod. June 14, 1897, the gage rod indicated a depth of 30 feet 1 inch in the reservoir. August 3, at the beginning of the first run, the gage indicated 29 feet 10 inches, show-

ing a loss of 3 inches from the surface of the reservoir in one month and nineteen days. The following table shows the capacity of the reservoir between various contours:

Capacity of Cache la Poudre reservoir between contours.

Time of drawing off.	Remarks.	Cubic feet.	Gage reading.		Depth drawn off.	
			Feet.	Inches.	Feet.	Inches.
Aug. 3			29	10		
Aug. 3–8	Run out	15,279,696	29	3		7
Aug. 8–15	Leaky gates	329,218	29	1⅛		1⅛
Aug. 15–18	Run out	22,882,400	28	3⅛		10¼
Aug. 18–24	do	58,663,200	25	7½	2	8
Aug. 24–29	do	65,996,096	21	3⅜	4	3⅛
Aug. 29–Sept. 4	do	60,505,248	16	8	4	7⅜
Sept. 4–10	do	34,473,900	13	3⅛	3	4⅛
Sept. 10–14	do	14,122,000	10	7⅛	2	8
Sept. 14–Oct. 1	do	38,141,200				
Oct. 1–3	do	1,396,800	0	10		7⅛
Total		311,789,758				

NOTE.—The holding capacity at 30 feet on gage is estimated to be 358,000,000 cubic feet, while the amount drawn out when gage read 29 feet 10 inches was 311,789,758 cubic feet, showing a difference of 12 per cent by the two methods of measurement.

The supply ditch of this reservoir heads in the north bank of the river about 1 mile below Fort Collins. It has a width on the bottom of 10 feet, is 4 feet deep, and has a grade of 2.12 feet per mile, with an estimated capacity of 140 cubic feet per second. Its length from its headgate to the reservoir is 5.75 miles.

The outlet canal runs directly from the reservoir to Canal No. 2, reaching the canal about 1.5 miles below its headgate. The length of this outlet canal is a little more than 3 miles. Its bottom width is 6 feet, depth 5 feet, with a slope of ½ to 1 and a grade of 12 feet to the mile. Its estimated capacity is 200 cubic feet per second.

The total cost of the reservoir and its outlet and inlet to date has been $154,100, or $18.75 per acre-foot of holding capacity, amounting to $51 per share of the capital stock. This is considerably above the average cost for reservoir water in the valley, which can be accounted for in part by the fact that the site was not one of those natural depressions that require only the cutting of an outlet and the building of a small and inexpensive embankment. The dam had to be built up from the bottom of the outlet.

The company has a decree entitling it to fill its reservoir to a depth of 27 feet, dated March, 1892, and a further decree entitling it to fill the reservoir to an additional depth of 3 feet, dated August 4, 1894, making a total depth of 30 feet. These decrees are subsequent to those of the Windsor Reservoir and the Water Supply and Storage Company for storage, and also to all appropriations for direct irrigation. There being no appropriations for storage below the supply ditch for this reservoir, it is entitled to all the water which reaches its headgate, which is not needed for direct irrigation. Except during the

flood early in summer, the water supply consists mainly of seepage water entering the river between its headgate and the next above and the water used by the Hottel Mill at Fort Collins. The mill is entitled to 60 cubic feet per second, and when the mill is running by water power the supply comes down to this canal. When the mill has not demanded this water it has been diverted by other canals above; but in a recent decision the State supreme court held that this water must be allowed to flow down to this inlet ditch whether the mill uses it or not.[1]

Prior to 1897 it was the custom of the superintendent of the reservoirs, on application of a limited number of water-right holders for reservoir water, to set a date when the gate would be raised and when closed, generally including from four days to a week between the dates. This method did not give general satisfaction, as it often compelled a man to use his water when he was not ready or when he did not need it. Therefore the water could not be made to do the best service to the greatest number of water-right holders. Local rains might occur in one portion of the district (25 miles in extent) and none in others in the meantime. In 1897 the company changed this plan and adopted the following by-law, which gives entire satisfaction to the patrons and results in a great saving of water:

RULE 31. Whenever the owners of 200 shares of the capital stock of the corporation on which all valid assessments shall have been paid shall demand, either in person or by proper order, the delivery of all or a part of their pro rata share of the water stored in the reservoir or reservoirs of this corporation, the board of directors shall cause the water so demanded to be delivered into the canal of The New Cache la Poudre Irrigating Company or Lake Canal, to which it may be ordered to be delivered by the several stockholders: *Provided*, That whenever water is emptied from the reservoir or reservoirs it shall be at the rate of 1 cubic foot per second for each 8 shares of the stock representing the water for which demand is made; except that the owners of 100 shares of the stock of the corporation demanding water to be delivered into the Lake Canal will be sufficient to cause the board of directors to grant an order of delivery in accordance in all other respects with the foregoing conditions of this rule.

When the demand falls below 25 cubic feet per second the reservoir gates are closed. The present system does not require one irrigator to prorate his water with others. He can take his share of water in the reservoir all at one run, or a part of it at a different time, as he chooses.

Before the water is drawn from the reservoir each water-right holder is credited with his pro rata share, and a record is kept of the quantity received by him. No one is allowed to overdraw his account.

As has been stated, the reservoir and canal companies are separate organizations. The delivery of water from the reservoir to the lands of the consumers is performed by the canal company, for which it

[1] 62 Pacific Reporter, p. 420.

charges and collects $10 per annum for each water right. This tariff provides a fund which largely pays the expenses of operating and maintaining the canal.

It may be well to state that during late irrigation the canal is often carrying water from the river and from the reservoir at the same time. Usually the river water is prorated among the consumers; so, as a rule, the irrigator is using two kinds of water for his late irrigation, or, rather, there are two different quantities to be accounted for, one quantity to be prorated with others, and the quantity from the reservoir which he has "checked" out is to be added to his pro rata share.

While the system of dividing and measuring water from this canal is not strictly accurate, it has always given general satisfaction when properly administered.

It often happens that some water-right holders in the reservoir have but little or no use for water for late irrigation. These generally find opportunities to dispose of their reservoir water for the season. The price for 800,000 cubic feet ranges from $20 to $40, according to the demand or scarcity of water. If the average price was $30, it would be at the rate of $1.63 per acre-foot at the reservoir. These figures do not include the tax of $10 per water right charged by the canal company for delivery. This is paid by the purchaser of the water.

THE WINDSOR RESERVOIR.

The Windsor Reservoir is a private reservoir, owned and operated by ex-Governor B. H. Eaton. It was at first intended to furnish water for his lands lying below a line surveyed for a canal from its outlet. After the project was started the plan was changed. Owing to the fact that a comparatively small amount of the land of its owner was tributary to the proposed outlet canal, and to the great length of canal necessary to reach the most distant portions of the land, and, further, to the fact that the reservoir site was capable of being developed to a far greater holding capacity than was at first intended, it was decided to abandon the outlet, increase the size of the reservoir, and connect it with the Cache la Poudre Canal, which lies below it and has a right prior to that of the Larimer and Weld Canal for water from the river. The plan to exchange water from the reservoir for river water to be taken into the Larimer and Weld Canal was agreed to by both companies. This enabled Mr. Eaton to dispose of the water from his reservoir for a like amount to be taken out of the river through the Larimer and Weld Canal, thereby enabling him to serve all his lands and to do away with the building of the outlet canal, as he at first planned.

The decreed appropriation of the Larimer and Weld Canal is 720 cubic feet per second. In order that water for storage might be run through the canal at the time it was drawing the full appropriation, it

was enlarged from its head down to the point where the water is taken into the reservoir—a distance of 15 miles. This enlargement is said to have increased the carrying capacity to 1,000 cubic feet per second. The canal company charges $50 per annum for carrying the reservoir water in this enlarged section of the canal.

The Windsor Reservoir is situated about 3½ miles north of Windsor and close to the line of the Larimer and Weld Canal. The area of the surface at 28 feet above its outlet is 700 acres, and it has a holding capacity of 610,000,000 cubic feet, or 14,004 acre-feet. It receives its supply of water through two sets of inlet gates, located some 500 feet apart, on the right bank of the Larimer and Weld Canal. (See Pl. IV.[1])

The site covers and includes one of the natural basins before described, also a slight depression in a small valley, in which, at a narrow place, was a suitable place for the reservoir dam. The bottom of the basin was several feet lower than the depression in the valley. The basin and depression were connected by a cut 24 feet deep through the dividing ridge. No attempt was made to draw water from the lowest point of either basin, and it is estimated that there are 150 surface acres of "dead" water below the outlet of the reservoir. The embankment forming the dam of the reservoir rests on the crest of a slight ridge crossing the valley, and a cut 17½ feet deep was made for the outlet conduit.

The embankment is made of earth obtained near by, both from the inside and outside of the reservoir. The top is 34 feet above the bottom of the outlet. The inside of the embankment is protected by brush, straw, wire fence, and anything convenient that will answer the purpose. (See Pl. VII, fig. 3, p. 34.) While this form of riprapping does not present a very attractive appearance, it answers a temporary purpose quite well, for it is the intention of the proprietor to raise the embankment several feet higher for the purpose of increasing the holding capacity to nearly or quite 1,000,000,000 cubic feet.

THE LARIMER AND WELD RESERVOIR.

The Larimer and Weld Reservoir Company is a stock concern which is organized, controlled, and managed much the same as the Cache la Poudre Reservoir Company, before described. Stock is sold only to stockholders in the Larimer and Weld Canal, though not all stockholders in the canal have reservoir stock.

The reservoir is situated about 2 miles north of the city of Fort Collins, and lies just above the Larimer and Weld Canal, through which

[1] Plate IV shows one of the inlet gates of the Windsor Reservoir. The gate at the top of the view is in the bank of the Larimer and Weld Canal. The pool into which the water falls is the surface of the reservoir when filled. The drop as shown in the view is about 30 feet. The gate is capable of discharging 500 cubic feet per second.

its water is distributed. The canal is so nearly on a level with the outlet of the reservoir that water backs into the outlet from the canal when it is running full, as shown in Pl. VIII, fig. 2, p. 34.

The reservoir occupies what was once Terry Lake. This little lake occupied one of the many small natural basins to be found in that immediate vicinity, and, being surrounded by irrigated land, it became filled with water, with no visible outlet. This little basin was within a larger one, and the reservoir is the combination of the two, and has been added to by building an embankment 32 feet above the bottom of the outlet gate.

The area covered at high-water line is 470 acres, and the holding capacity is 350,000,000 cubic feet, or 8,035 acre-feet. This supply is obtained from several sources, such as seepage and storm water from Dry Creek, the drainage and seepage water that formed and supplied Terry Lake, and also from several water rights in one of the first canals taken out of the river above Laporte. These have never failed annually to fill the reservoir.

The cost of the reservoir and all its accessories was $65,000, which was raised by two assessments on the shares then sold—the first of $200 per share, the second a little less than that. The cost per acre-foot of holding capacity is $8.09. In January, 1900, there were 187 water rights sold, making a cost of $347.60 per water right. The present selling price of these is from $900 to $950.

The canal company charges $1 per million cubic feet for carrying reservoir water.

Both companies permit the transfer or exchange of reservoir water between stockholders upon application made three days in advance, provided its delivery will not overtax the lateral ditch through which it is to be drawn. The reservoir, when full, will supply to each water right 1,871,657 cubic feet, or very nearly 43 acre-feet, a little more than 6 inches of water on the 80 acres represented by a water right. This is more than is furnished by some of the other reservoirs, because of the small number of shares sold. The fact that the proprietor of the Windsor Reservoir owns about one-third of the land under the Larimer and Weld Canal accounts in part for the small number sold.

THE WATER SUPPLY AND STORAGE COMPANY'S RESERVOIRS.

This company owns and controls a greater number of storage reservoirs than any other company in the valley. These reservoirs are in two groups—upper and lower.

The upper system consists of a series of small reservoirs in the mountains at or near the head of the Cache la Poudre River, the largest of which is Chambers Lake. The water from these reservoirs is discharged into the main river and is taken out about 70 miles below. The supply, both for storage in Chambers Lake and for the

Larimer County Canal, is reenforced by water brought from outside the drainage basin of the Cache la Poudre River, most of it coming from the head waters of the Laramie River through the "sky line" ditch, which conducts the water from the latter stream over the divide into Chambers Lake. This ditch is cut mostly out of the rocky slopes of the mountains. The carrying capacity of the ditch is 200 cubic feet per second at the head and 350 cubic feet per second at the lower end. It is estimated that 700,000,000 cubic feet of water have been turned into Chambers Lake through this ditch during the present season up to September 1. The ditch was built in 1893, and cost $90,000. Further small supplies are obtained from Michigan Creek, a tributary of the North Platte River, and from small creeks which are tributary to the Grand River. This last supply is taken from streams that lead into the Pacific Ocean through the Gulf of California. The turning of the waters of one watershed into another, as in these instances, has been carried on for many years, and in 1897 was sanctioned by law.

Chambers Lake is really the source of the river. Its elevation above sea level is 9,300 feet. It lies in a little nook in the eastern slope of Medicine Bow Range. It was probably at one time the end of a glacier, which pushed a deposit of rock débris and gravel in front of it and formed the rim on the eastern side of what is now a natural basin of about 100 acres, but was much larger at one time. Three creeks enter the basin on its western and southern sides. The material which these have brought down has filled up the south end of the basin, making it a flat marsh almost on a level with the natural outlet of the lake. This outlet was closed in 1870 for the purpose of flushing the river in times of low water, in order to drive logs and railroad ties down to the plains. This company obtained a right under the law, in 1881, to build a higher dam for reservoir purposes. In that year a dam 17 feet high was built, which impounded 134,176,800 cubic feet of water. In 1891 the dam was destroyed in consequence of an insufficient or improperly constructed spillway. The dam was rebuilt the next year, it being at the present time capable of raising the water 11 feet above the outlet gates, giving the lake a capacity of 54,857,336 cubic feet.

Just north of Chambers Lake and but a few feet above it is a flat, marshy country, that lies in the saddle of the divide between the Cache la Poudre and Laramie rivers. The beavers had built their dams across this marsh so high that some water was impounded here. The company raised these dams slightly higher and cut an outlet channel leading into the lake, which enabled them to store a few million cubic feet in addition to that held in Chambers Lake.

The company is supposed to turn out of Chambers Lake into the river the natural flow into the lake during the irrigation season and when the natural flow of the river is wanted by prior appropriators

for storage purposes. It will be seen that to comply with the law the natural flow of water into the lake and the flow out of it must be determined; also the amount of water stored in the reservoir, and also that which is turned into it from other watersheds. All must be determined by measurements, so that the company and the public will have the data from which to divide the water in the river at the head of the company's canal or at any other place the company may choose to take its water from the river. Up to the present the company has been in charge of the measurement of water in this locality, and keeps a man for that purpose, who receives orders from headquarters at Fort Collins regarding the amount of water to let out of the reservoir for the use of the company.

The lower system of reservoirs is all supplied from the river through the canal of the company, the Larimer County Canal, and are all below the line of the canal, and some of them are below the lands of the farmers holding stock in the company. The reservoir water is made to serve these lands by means of the exchanges of water, which will be explained later.

The six reservoirs of the lower system occupy natural depressions and basins that lie out on the plains. None of them required high embankments or long and expensive outlets, and the cost of construction per acre-foot of holding capacity is nearly as low as any in the valley, not including the North Poudre system. Nearly all these reservoirs lie in one group and are connected with channels leading from each to the next lower. No. 1 or Rocky Ridge is immediately on the upper side of the canal that supplies it. The outlet is a tunnel under the canal, as shown in Pl. VIII, fig. 3, p. 34.

The combined capacity of Chambers Lake and the six reservoirs in the lower group is 550,813,104 cubic feet, or 12,645 acre-feet. The estimated cost of the improvement of these reservoirs is $50,000, or $3.95 per acre-foot of holding capacity.

The capital stock of this company is $60,000, divided into 600 shares at $100. Each share represents a water right, or one six-hundredth of the canal, reservoirs, and appurtenances, as well as one six-hundreth part of the water in the reservoirs or carried by the canal, for distribution. Therefore the water carried by the canal, whatsoever quantity it may be, is prorated. Assessments are made on the stock for extensions, enlargements, renewals, repairs, superintendence, and other legitimate expenses. It is not the intention of the company to issue more than 600 shares.

This company is organized on the community plan, something after the Cache la Poudre Canal Company, except that the Water Supply and Storage Company owns and operates the canal and reservoir system as one concern.

THE NORTH POUDRE RESERVOIR SYSTEM.

The arable lands covered by the North Poudre Canal and reservoirs lie in the extreme northwest corner of the plains section of the State, east of the front range of the Rocky Mountains. The only water available for this section is from the North Fork of the Cache la Poudre, whose water supply is from the mountainous country lying on the eastern side of the low divide between the Cache la Poudre and Laramie rivers. In the adjudication of water rights the North Fork was made a part of the main stream.

The North Poudre Canal is the only canal or ditch of any size taking water from the stream. Under this canal is one of the largest groups of natural basins in the State. It was the practicability of cheaply improving these reservoir sites that led to the inauguration of the irrigation enterprise, the promoters believing that the North Fork would supply sufficient water during the year to irrigate a large body of land if all the water was stored in the reservoirs which lie under the canal. It is quite probable that the promoters failed to take into consideration the fact that their appropriation was subsequent to most of those on the main stream. In the division of water in the streams by the water commissioner he has generally duly considered the priority of this canal and dealt with it accordingly, and the result has been that on account of a shortage of water there has not been the steady and gradual development of the country tributary to this canal and the reservoirs that there has been elsewhere in the valley.

It is claimed that this irrigation system is more valuable for storage purposes than for direct irrigation from the canal, on account of the part it may play in the general exchange of water in the valley. Already it has been connected with two of the other systems.

It will be noticed in the table giving the cost per acre-foot for impounding water in the reservoirs under discussion that this group is much lower than any other given. This is due to the natural depressions forming so large a percentage of the entire holding capacity; also to the short outlet cuts through their rims.

There are six of these natural basins improved, which altogether have a holding capacity of 1,137,188,484 cubic feet, or 26,106 acre-feet. The cost of improving the entire group is given as $25,500, or 98 cents per acre-foot of reservoir capacity. There is no better construction work done on any of the reservoirs in the valley than on the four of these which are completed. Their banks are made of good material, with quite flat slopes on the inside, and the faces of the embankment are riprapped with stone. The outlet gates, pipes, and conduits are all substantial and durable structures, which reflect credit on the proprietors and the engineer.

These reservoirs are all below the canal, but serve a considerable area of land belonging to the proprietor of the canal. The two

largest, Nos. 5 and 6, are, however, below all the lands served by the canal and can be utilized only by exchange. These two reservoirs have been completed during the past season and have never been filled. The canal supplying them has a scant water supply, and it remains to be seen whether water can be obtained to fill them. This condition of things has sent their engineers into the mountains to explore. The result has been the discovery of a practicable route for taking water from a stream in another watershed into the North Poudre to supply this canal. The quantity of water which can be obtained annually from this source has not yet been determined, but the projectors confidently expect to secure sufficient water from this source to fill at least one of these reservoirs each season. If this can be done, it will greatly extend the utility of this group of reservoirs.

The data regarding the principal reservoirs in the Cache la Poudre Valley are summarized in the following table:

Tabular summary of data regarding reservoirs in the Cache la Poudre Valley.

Name of reservoir.	Surface area.	Holding capacity.		Total cost.	Cost per acre-foot.
	Acres.	*Cubic feet.*	*Acre-feet.*		
1. Cache la Poudre *a*	520	358,000,000	8,212	$154,100	$18.75
2. Windsor *b*	700	610,000,000	14,004	50,000	3.57
3. Larimer and Weld (Terry Lake) *c*	470	350,000,000	8,035	65,000	8.09
4. Larimer County system: *d*					
Chambers Lake	.....	54,857,336	1,259	.....	.....
No. 1 (Rocky Ridge)	226	205,853,620	4,726	.....	.....
Nos. 2 and 3	128	44,659,068	1,025	50,000	3.95
No. 4	83	43,369,500	996	.....	.....
No. 5 (Long Pond)	230	170,855,000	3,922	.....	.....
Lindenmeier Lake	106	31,218,580	716	.....	.....
5. North Poudre Group: *e*					
No. 1	80	29,345,491	674	3,000	.....
No. 2	240	145,355,180	3,337	7,500	.....
No. 3	160	111,057,813	2,550	5,000	.98
No. 4	80	47,000,000	1,079	5,000	.....
No. 5	425	229,430,000	5,267	1,000	.....
No. 6	572	575,000,000	13,200	4,000	.....
Totals and average	4,020	.....	69,002	344,600	5.00

a Serves land under "Greeley No. 2" Canal, colored green on map, Pl. XI, p. 38.
b Belongs to B. H. Eaton, farming lands chiefly under Larimer and Weld Canal, colored blue on map.
c Serves land under Larimer and Weld Canal, colored blue on map.
d Belongs to irrigators under Larimer County Ditch; lands colored red on map.
e Belongs to the owner of North Poudre Canal; lands colored yellow on map.

OTHER RESERVOIRS.

The reservoirs above described all serve lands on the north side of the river. Their holding capacity, as given above, is, approximately, 69,000 acre-feet. The area tributary to the reservoirs and which can be reached by the canals distributing their water is about 125,000 acres.

On the south side of the river there are two small reservoirs improved and in use. These lie in the midst of the farming lands near the mountains. One of these, Claymore Lake, is supplied with water from a canal which takes its supply from the river just as it emerges from

the canyon. This reservoir occupies a slight depression, with a low embankment on its lower side, which raises the water to about 4 feet above the outlet. At this height it covers an area of about 69 acres, and has a decreed holding capacity of 39,000,000 cubic feet.[1] Its main value is to reenforce the lower end of the canal in times of short water. This reservoir is used in a small way in the exchange of water on the river. It shows more loss of water than any other reservoir in the valley of which we have any note. This is probably due to the fact that there is no irrigation above the canal or reservoir to furnish seepage water, and also to the fact that it is situated at the foot of a rocky ridge, where the subsoil in the basin forming the reservoir is probably a deposit of decomposed rock of a coarse texture, which does not hold the water which percolates through the thin lining of its sides and bottom.

The other reservoir, known as the Warren Lake Reservoir, is situated some 3 or 4 miles southeast of Fort Collins. This is the only reservoir in the valley which received a decree when the rights on the river were adjudicated in 1882. It occupies a natural depression, having a slight embankment on the lower side. It was first filled with seepage water and with waste from the end of a canal. It was for several years used for fishing and boating, being stocked with fish by the United States Fish Commission. Later a slight cut was made to draw off 2 or 3 feet of water, which was used for irrigation. Recently the banks on the lower sides have been raised and a substantial wall to protect these banks has been made. The reservoir now covers 119 acres, and its holding capacity is, by the decrees, 29,304,990 cubic feet. This water is now used for late irrigation, principally on potatoes and the third crop of alfalfa.

Farther from the foothills and below most of the irrigable land on the south side of the river, and on the divide between the Cache la Poudre and Big Thompson rivers, are some sites which have been filed on, some of which are being improved. One system of these, on which some work is being done, is known as the Seven Lakes Reservoir. These lakes can be filled from either stream, and can be used on the lands in both valleys. Their capacity, as shown by the filings in the office of the county clerk, is 330,000,000 cubic feet, or 7,575 acre-feet. The company which is developing these reservoirs is composed of water-right holders under the Loveland and Greeley Canal, which takes its water from the Big Thompson River; but the location of the basins is such that they can serve lands either under the Loveland and Greeley Canal or under the Greeley No. 2 and No. 3 canals from the Cache la Poudre.

Immediately adjoining on the east and below this group of reser-

[1] Recorded in Larimer County clerk's office—which is probably an error.

voirs, which is about 10 miles southeast of Fort Collins, is the largest natural basin in the Cache la Poudre Valley, known as Boyd Lake. This is one of the reservoir sites examined by Capt. H. M. Chittenden, of the United States Corps of Engineers, in 1897, in compliance with an act of Congress making an appropriation for examining reservoir sites, making estimates of their cost, publishing maps, etc. Captain Chittenden estimated that this reservoir without any artificial embankments would have a surface area of 1,920.4 acres, with a maximum depth of about 44 feet. This would give a holding capacity of 1,992,468,378 cubic feet, or 45,740.7 acre-feet. The estimated cost of the reservoir, including right of way, extinguishment of present rights, construction of outlet, etc., is $262,106.34, making a cost of $5.73 per acre-foot of holding capacity. This estimate of the cost, which is considerably below that of some of the reservoirs already improved, is considered by many to be too high, as it could be reduced greatly by not cutting so deep an outlet as was figured on in the estimate, which does not justify the expense for the increased holding capacity. This basin could be filled from both the Cache la Poudre and Big Thompson rivers. Most of its waters would have to be drained into the Cache la Poudre Valley, and it could be turned into the river a little above the head of the Greeley No. 2 Canal, and so be made to serve lands under that canal and the Greeley No. 3. The improvement of this reservoir site was not recommended by Captain Chittenden, because there was no visible supply of water to fill it. Others claimed, however, that it could be filled almost every year during the flood season if the four ditches that now take water from the Cache la Poudre and Big Thompson rivers to the vicinity of the reservoir were enlarged so as to enable them to carry the surplus flood waters. Considering what has been accomplished in the last eight years in storing water, and the fact that the above-described reservoirs, having a combined holding capacity of 69,000 acre-feet, have been filled and emptied each year, and more or less water escapes unused each season, it would seem that the limit of storing water is not yet reached.

This year the river was above its normal height during May and June, and it is estimated that after all the canals were supplied there was sufficient water running to waste for several weeks to have filled all the present improved reservoirs in less than seven days. It is not expected that such a surplus of water will occur more than once every five to ten years, but there is scarcely a year passes in which some water does not escape unappropriated, either in the flood season or during the winter. While it would not be advisable to depend upon these two systems of storage at first for the sole supply of any considerable area, the time has come when one of them at least can be utilized to take care of the surplus, whatever it may be, and hold it for late irrigation purposes. The prediction in 1875 that there was at

that time a sufficient number of ditches and canals taken out of the river to justify stopping the construction of any more was probably no further from the truth than it is to say to-day that the storage of water has reached its limit.

RESERVOIR EMBANKMENTS AND OUTLET CONSTRUCTION.

With one exception all the reservoirs described have their outlets partly in the natural earth and partly in embankment. As heretofore stated, the outlets are never placed so low as to entirely drain off all the water. There are several reasons for this. The principal one is that the expense of making the cutting to the very bottom is not justified by the small amount of water obtained. Another is that reservoirs sooner or later become stocked with edible fish, and to preserv them more or less water is required at the bottom of the reservoir and, again, there is always some scouring of the inlet ditches, the material from which finds its way into the bottom of the basin. As long as this and the silt from the river is deposited below the level of the outlet there is no diminution of the holding capacity of the reservoir.

With one exception all of these reservoirs occupy natural basins or depressions in the country. Their holding capacities were increased by building embankments on the natural surface at the lowest parts of the rims of the basins. This point is generally the most suitable place for the outlet. Usually the first thing done is to establish the bottom of the outlet and make the cutting through the rim. The banks of that part of the cutting which is to be occupied by the conduit are left as nearly perpendicular as the ground will admit with due regard to safety from sliding in during the construction of the conduit. The cut above and below the conduit is sloped to about 1 to 1, and the material from this part of the outlet cut is generally put into the required embankment. After the conduit is laid the material that came out of that part of the cut is carefully put back and packed as firm as possible. If this material is not suitable for packing around the conduit, so as to be water-tight, suitable material obtained elsewhere should be used. This part of the work is usually done by hand. The embankments are made with plow and scrapers, and are carefully built up in layers and well packed by driving the teams over the entire surface. The slopes on the inside are made from 2½ to 1, to 4 to 1. The outsides are usually made from 2 to 1, to 3 to 1. The top widths are from 15 to 20 or more feet, and are made higher in the center to compensate for the settlement which is sure to occur when the water reaches the embankment.

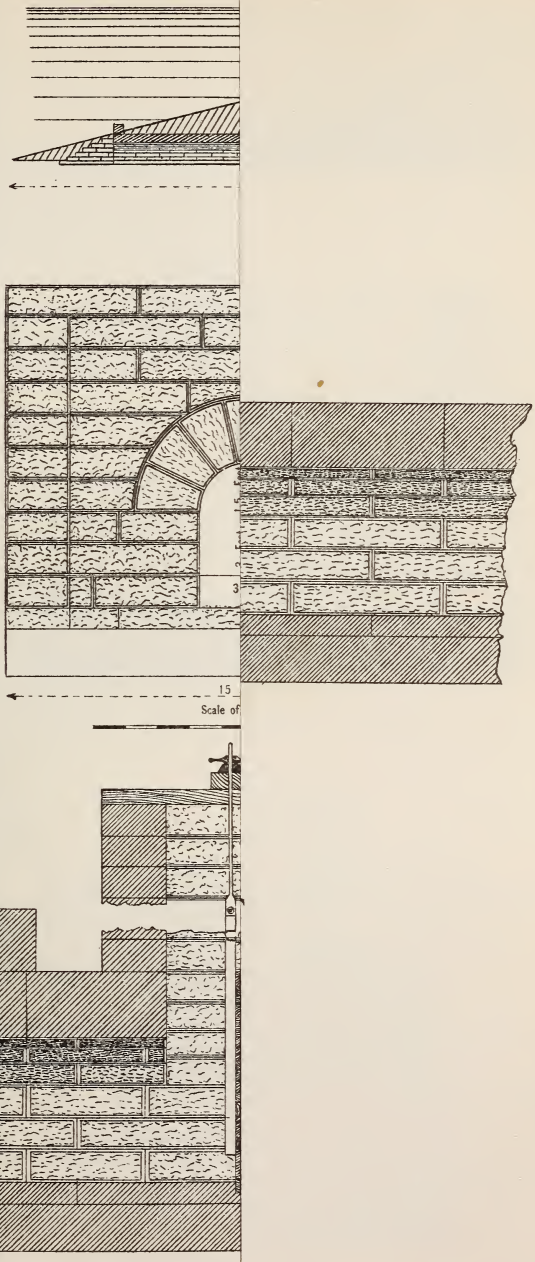
Two kinds of material are used in forming the outlet conduits. The most common is stone masonry (see Pl. V). The other is iron pipe (see Pl. VI). It is scarcely ever required to draw off water faster

than 250 cubic feet per second, and the size of the outlet is usually planned for more than that capacity when the reservoir is full or nearly so.

When the outlet cut is in common earth it is the practice to put in a concrete bed about 1.5 feet thick at the bottom of the trench and a little wider than the outside walls of the masonry conduit. On this is bedded a slab of flagging 6 to 8 inches thick and as long as the width of the concrete. This flagging is usually from 4 to 5 feet wide, making a floor with joints 4 to 5 feet apart, which are calked with oakum, then filled with neat hydraulic cement. The walls rest on the floor and are carried up about 3 feet high and an arch of 1.5 feet radius turned. The walls and the arch are 2.5 feet thick, built of Fort Collins flagging of various thicknesses, laid in hydraulic cement. The outlet and regulating gates are either placed at the upper end, as in Pl. X, p. 34, or back in the embankment to about the high-water line of the reservoir, as shown in Pl. VI. In this case the gates are opened through a masonry wall carried up from the conduit to about 4 feet above the high-water line. The gates are usually made of wood, and are generally operated by a screw. The upper end of the conduit is provided with a rack or grating to prevent the gates from getting clogged. Concrete collars surround the conduit at suitable intervals to prevent the water creeping along the sides (see Pl. V). The iron-pipe form of outlet is shown somewhat in detail in Pl. VI. The pipes rest on a bed of concrete, and are surrounded by concrete collars at the joints. The pipes represented in the figure are "flanged" and bolted together. This is the kind used on the North Poudre group of reservoirs, where the valve is placed at the lower end. Some of the same group have the same outlet valve on the upper end. In that case they are operated from an open tower of wooden timbers extending above the high-water line with a platform which is connected with the embankment by a wooden bridge. This kind of construction is not considered as good or as convenient as that having the valve at the lower end. The greatest objection is to the exposure of the tower to the damaging effects of ice in winter if much water is in the reservoir.

The only reservoir of the series under consideration which requires a wholly artificial impounding dam or embankment is the Cache la Poudre, shown in Pl. VII, p. 34. This has a masonry outlet with a regulating gate of a peculiar design, using an inclined track upon which a car runs which carries an iron plate or gate, and when "home" covers the iron face of the upper end of the outlet conduit. The opening, closing, and regulating of this gate is performed by a system of pulleys and wire ropes. At the beginning of the first attempt to draw off the water the gate failed to open, through some fault in its construction, and weeks of time and hundreds of dollars were spent in vain attempts to open it. The company finally had to

INLET GATE TO WINDSOR RESERVOIR.



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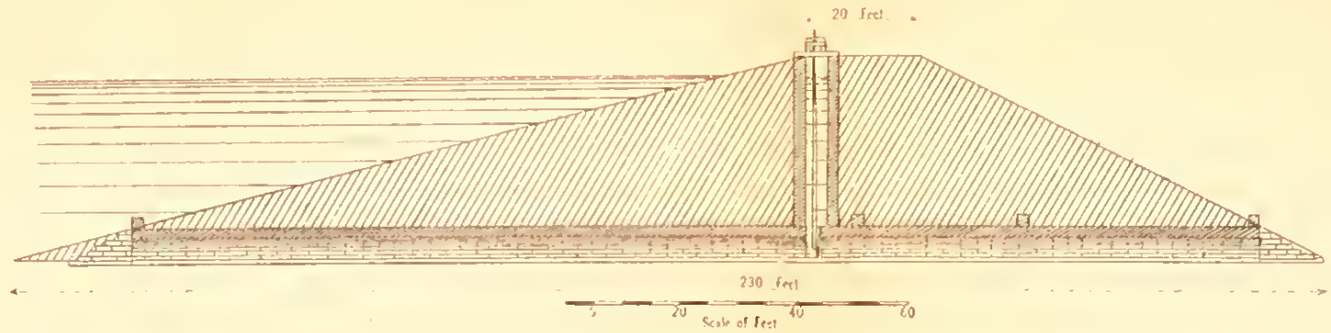

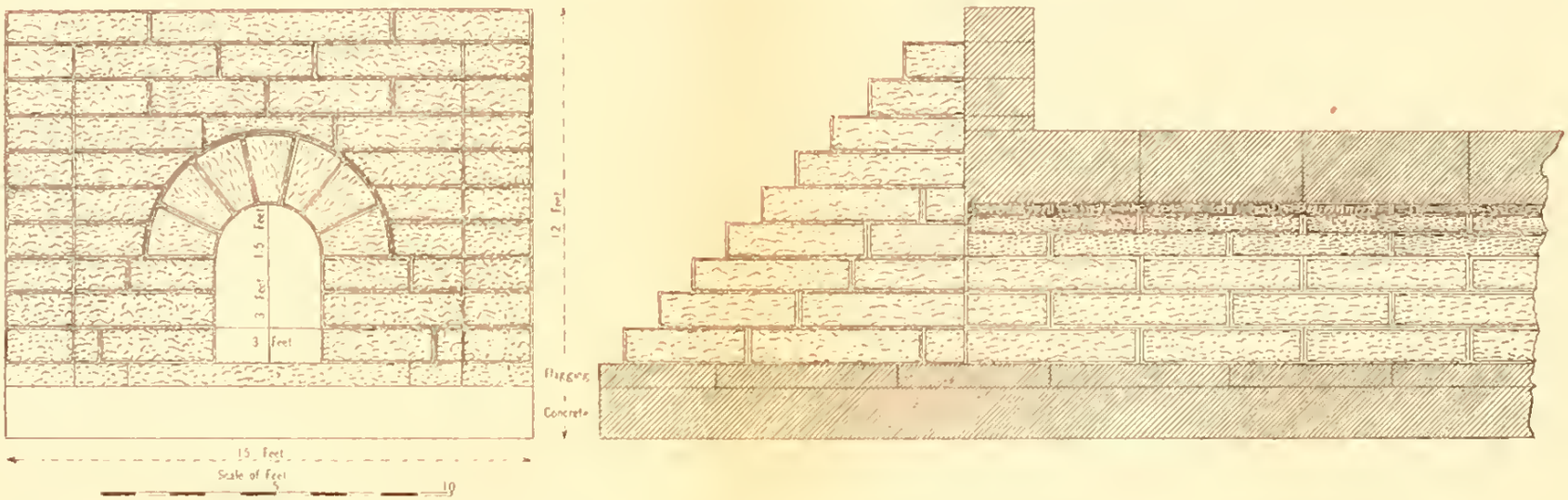

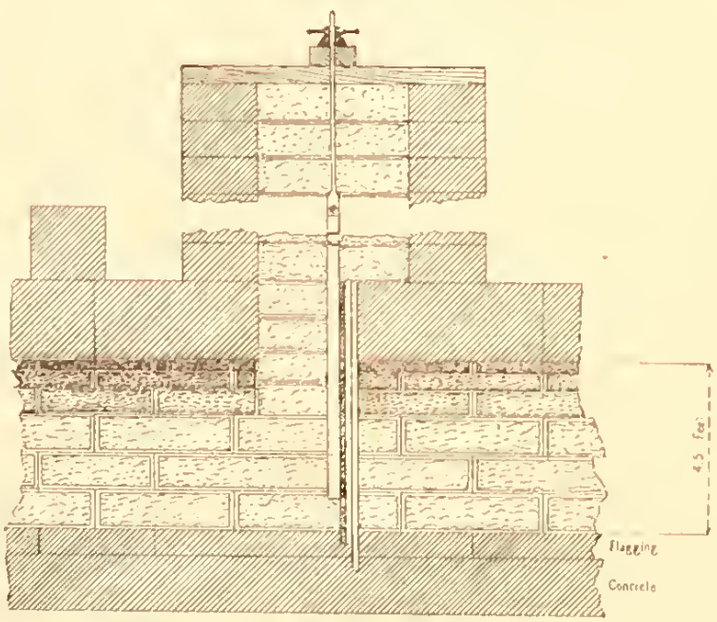

DESIGN OF
MASONRY ARCH
RESERVOIR OUTLET
IN COMMON USE IN THE
CACHE LA POUDRE VALLEY

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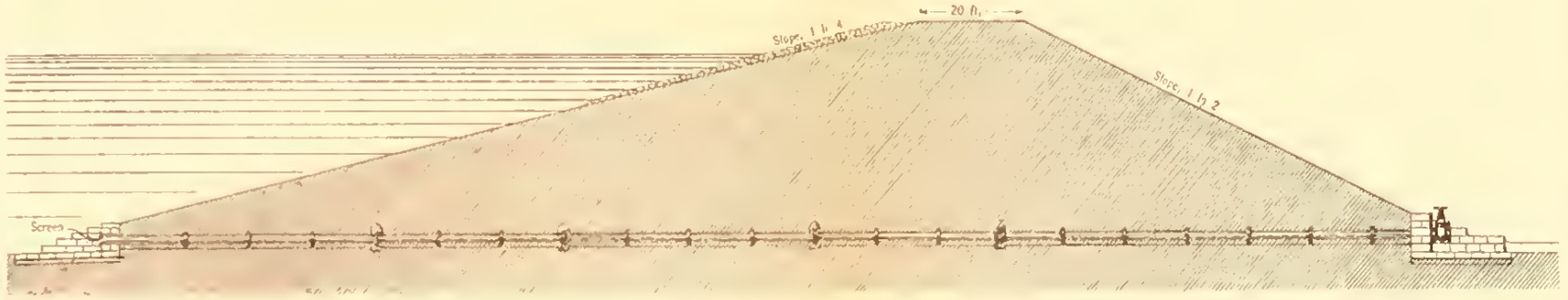
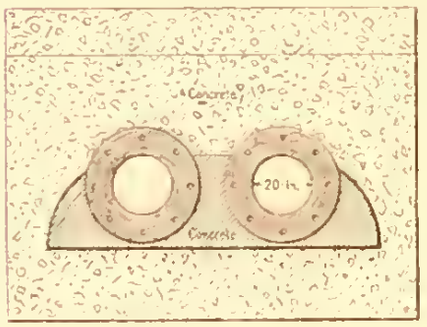
DESIGN OF MASONRY ARCH RESERVOIR OUTLET.

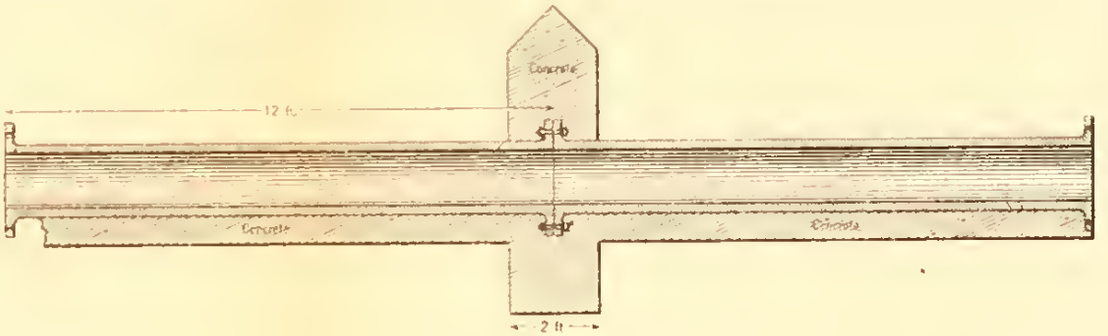
DESIGN OF
CAST IRON PIPE
RESERVOIR OUTLET
IN COMMON USE IN THE
CACHE LA POUDRE VALLEY

CROSS SECTION OF DAM

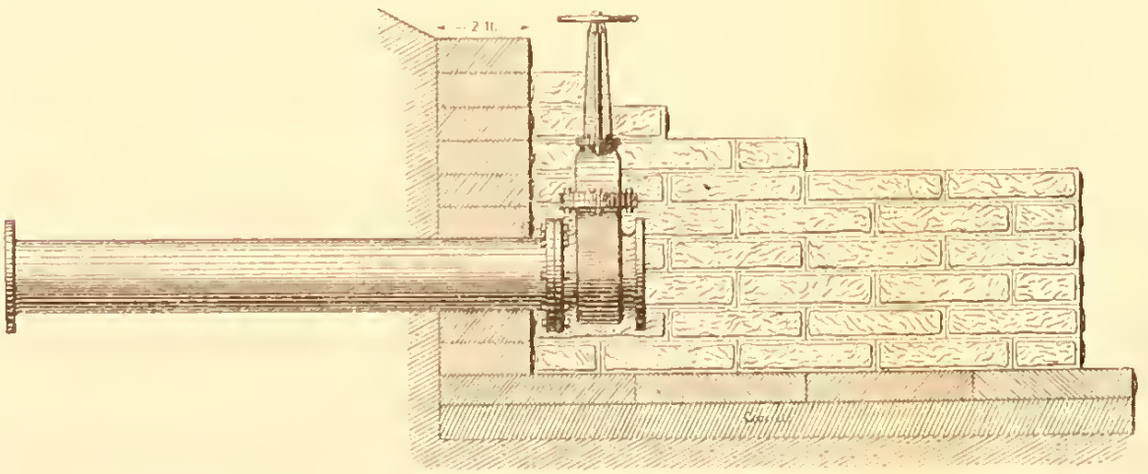


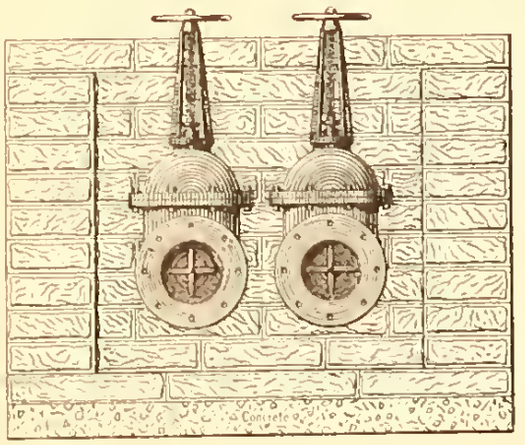
DETAILS OF CONCRETE COLLARS





DETAILS OF OUTLET VALVES





THE HORNS PETERS CO. PHOTO-LITHO. WASHINGTON, D. C.

DESIGN OF CAST-IRON PIPE RESERVOIR OUTLET.

employ a diver from St. Louis with his paraphernalia to help them out of their trouble, but not until their crops had suffered greatly for water.

There is no necessity for riprapping the whole face of the embankment. The slope should be protected a few feet above the high-water line and a short distance below, but it is useless to carry it to the very bottom, for the reason that when the time comes for using reservoir water it is generally drawn off quite rapidly and at a time of year when there are no winds to do any harm.

No accidents have occurred to any of the reservoirs occupying the sites of the natural basins or depressions. Probably the nearest approach to what might have resulted in a serious accident has been the washing of the banks during the high winds in the spring months.

One precaution against the possibility of an accident to masonry outlets ought to be taken that is not. The inside of every masonry conduit ought to be rigidly inspected each time the water is drawn off, to see if the joints in the stonework are tight and none of the stones have been loosened by the force of the water, particularly just behind the outlet gate. A small leak there is sure to prove a serious matter in a very short time.

A better idea of the construction of these reservoirs may be had from a study of Pls. VII–X.

Pl. VII, fig. 1, shows a portion of the embankment of the Cache la Poudre Reservoir, also the southwest corner of the reservoir when filled. It also shows the protection of the inside of the embankment against washing. This consists of a single row of piles planked up on the bank side and filled in behind with loose rock.

Pl. VII, fig. 2, shows the lower end of the outlet of the Cache la Poudre Reservoir and a section of the embankment at its highest point. The regulating gates are at the upper end of the conduit. The style of construction shown here is the same as that of nearly all the stone conduits that are used as outlets. The arches are turned with a single course of 24-inch flagging. The floors are laid in concrete beds, and are made of heavy flagging long enough to reach from outside to outside of side walls. The whole is laid in hydraulic cement. It will be observed that this outlet is about level with the surface of the ground. This is the only reservoir in the valley where no cutting has been required to take the water out. The impounding dam, which is 30 feet high, is all embankment.

Pl. VII, fig. 3, shows the inside of the embankment of the Windsor Reservoir and the temporary brush protection against wave action. It also shows the means of operating the outlet gates. The gates are at the upper end of the conduit and are raised by the screw shown in the view.

Pl. VII, fig. 4, shows the lower end of the outlet of the Windsor

Reservoir. It is planned to raise the embankment of this reservoir about 15 feet above its present height, which will require widening the base about 30 feet. This will be done mainly on the lower side, and will require an extension of the stone conduit to near the lower end of the wooden chute. At the time the view was taken there was about 200 cubic feet per second being drawn from the reservoir and discharged into the Greeley No. 2 Canal.

Pl. VIII, fig. 1, is a view of the interior of the Larimer and Weld Reservoir when nearly empty. The form of riprapping used is shown in the upper right-hand corner of the view. This view shows the upper end of the outlet shown in fig. 2. The top of the natural banks is about on a level with the bottom of the stone-wall protection.

Pl. VIII, fig. 2, shows the lower end of the outlet of the Larimer and Weld Reservoir. The water from the Larimer and Weld Canal has backed in and covers the opening. The gates are located about the middle of the conduit and are reached by a stairway in a masonry well.

Pl. VIII, fig. 3, is an imperfect view of the lower end of the outlet of Rocky Ridge Reservoir, or No. 1 of the Water Supply and Storage Company's system. This outlet is a tunnel through a rock ridge which forms the lower embankment of the reservoir and carries the Larimer County Canal. The man in the view is standing on the right bank of the canal. On the other side of the canal is the reservoir. The dark line about 7 feet below the man is about the level of the bottom of the ditch and of the surface of the reservoir when filled. The material from the dark line down is solid rock, just wide enough at this point for the canal. On the other side the natural slope of the rock forms the wall of the reservoir. The inlet from the reservoir to the canal and the outlet gates from the reservoir are on the other side close together.

Pl. VIII, fig. 4, is a view of the outlet cut of reservoir No. 3 of the North Poudre group. This is a type of reservoir which requires a long and deep cut to draw off the water. It will be noticed that there is very little embankment except that required to fill the cut. The outlet through the embankment is cast-iron pipe, 20 inches in diameter, with the regulating valve on the upper end. What appears to be some sort of a trestle is a small box flume, and has no connection with the reservoir or its embankment.

Pl. IX, fig. 1, is an inside view of the outlet of Long Pond or reservoir No. 5 of the Water Supply and Storage Company's system. This reservoir has no artificial embankment, the natural depression forming the entire reservoir. The outlet cut is about 30 feet deep, and in this a stone conduit is laid. The regulating gates are placed about one-third of the way down the conduit from the upper end, in the masonry well, shown in the view. The water in the cut which extends out to the reservoir, as shown in the view, is about 9 feet deep.

U. S. Dept. of Agr., Bul. 92, Office of Expt. Stations. Irrigation Investigations.

FIG. 1.—EMBANKMENT AND PILE PROTECTION OF CACHE LA POUDRE RESERVOIR.

FIG. 2.—LOWER END OF OUTLET OF CACHE LA POUDRE RESERVOIR.

FIG. 3.—INSIDE OF EMBANKMENT AND OUTLET OF WINDSOR RESERVOIR.

FIG. 4.—LOWER SIDE OF EMBANKMENT AND OUTLET OF WINDSOR RESERVOIR.

U. S. Dept. of Agr., Bul. 92, Office of Expt. Stations. Irrigation Investigations.

FIG. 1.—INTERIOR VIEW OF LARIMER AND WELD RESERVOIR.

FIG. 3.—OUTLET OF ROCKY RIDGE RESERVOIR.

FIG. 2.—LOWER END OF OUTLET OF LARIMER AND WELD RESERVOIR.

FIG. 4.—OUTLET OF NO. 3 RESERVOIR, NORTH POUDRE SYSTEM.

FIG. 1.—INTERIOR VIEW OF LONG POND RESERVOIR.

FIG. 2.—OUTLET CUT, LONG POND RESERVOIR.

FIG. 1.—CACHE LA POUDRE RIVER AT HEAD OF LARIMER AND WELD CANAL.

FIG. 2.—LARIMER AND WELD CANAL AND WINDSOR RESERVOIR.

FIG. 3.—HEADWORKS OF LARIMER COUNTY CANAL, FROM BELOW.

FIG. 4.—HEADWORKS OF LARIMER COUNTY CANAL, FROM ABOVE.

Pl. IX, fig. 2, shows the lower end of the same conduit as is shown in fig. 1. It will be noticed that the cut for some distance above the bottom is in rock and cemented gravel, and here the walls are nearly vertical. A short distance below the foreground in the view the ground slopes so rapidly down to the Larimer and Weld Canal that the water has to be carried down the incline in a flume which is carried over the above-named canal and discharges into Lindenmeier Lake just below.

Pl. X, fig. 1, is a view of the Cache la Poudre River taken June 15, 1900. It represents the diverting dam at the head of the Larimer and Weld Canal and the boom in front of the headgates. This boom is solely for the purpose of keeping the driftwood, etc., from entering the head of the canal. The discharge of the river at the gaging station at the canyon was 2,797 cubic feet per second at the time. The normal flow of the river at this date is 2,132 cubic feet, therefore the view shows the water a little above its average height in the middle of June for the past fourteen years. This point in the river is about 3 miles in an air line from Fort Collins.

Pl. X, fig. 2, shows the Larimer and Weld Canal about 17 miles below its head. The canal at this point is about 40 feet wide at the bottom and 50 feet wide at the water line, and is carrying about 700 cubic feet per second. The erosion of the banks shows plainly. The water seen in the distance is the upper end of the Windsor Reservoir. The trees are a volunteer growth of cottonwood about 18 years old.

Pl. X, fig. 3, shows the headworks of the Larimer County Canal, showing the diverting dam, headgates, and the appliances for operating them. At the time the view was taken there was 470 feet of water per second being taken into the canal.

Pl. X, fig. 4, shows the upper side of the same headworks that are shown in fig. 1. At this point on the river the fall is very rapid, as will be seen from the way the water strikes the outer corner of the structure. The life of a wooden structure of this description, situated as it is, is at best very short. This is the second structure erected within nine years. The next one will probably be of masonry and steel, which will in the end be cheaper than wood, and much safer.

WATER FOR FILLING RESERVOIRS.

The right to water for storage purposes is junior to that for direct irrigation—that is, when the water of a stream is needed to supply the canal for direct irrigation no water can be taken for storage purposes; therefore reservoirs can be filled or replenished only at such times as there is a surplus in the stream or at those seasons of the year when water for direct irrigation is not needed, as in the late fall or early spring months or in the winter season, making in all from six to seven months.

Decrees for water from the public streams for filling reservoirs are usually made by the courts, which establish the dates and orders of

appropriations. The water commissioner of the stream is supposed to recognize these orders of priority in his division of water for storage purposes, but not with the exactness that he does in the division of water to the canals. Since the building of reservoirs began in the Poudre Valley there has been no year that they have not been filled with the exception of the North Poudre group; therefore there has been little or no occasion for the water commissioner to look after the division of water for storage purposes.

It is not a good plan to fill reservoirs to the high-water mark in the early spring with the intention of holding the water over until required for fall irrigation. Even if there were no loss the wear and tear and damage to the embankments from the high winds liable to occur during this time will hardly justify it. Better take the chances of an opportunity to fill them to their high-water line during the flood later in the season.

A few years ago it was thought to be impossible to run water in canals during the winter season in Colorado, on account of the freezing weather and the drifting snows that frequently occurred there. In fact, it was impossible at that time. About twenty years ago the river began to show an increase in volume in its course down through the valley. This was very discernible in low water, and measurements were first made in October, 1885, to determine the amount of the increase, the cause, and where it came from. It was found that the flow of the river opposite the irrigated country was augmented by ground or seepage water coming into the river channel in the form of small springs just at the surface of the water. Measurements showed that, at the time, the seepage water entering the stream between the gauging station in the canyon and the mouth of the river equaled 68 per cent of the flow of the river at the canyon. Similar measurements for the same purpose have since been made, which show an annually increasing amount of seepage water finding its way into the river. The effect of so large a percentage of ground water entering the river at a temperature from 10° to 25° above the freezing point is to check the formation of ice to such an extent that during the coldest weather in winter ice has scarcely formed on the surface, when as late as 1875 ice was frequently a foot thick. On account of this rise in the temperature it was found practicable to run many of the canals through the entire winter. This is particularly the case where the canals lie below the irrigated country and on that account catch more or less of the warm seepage water, thus becoming running streams for miles down the line of the canal during the winter season. The process of settling a country modifies the winter storms and drifting snows to such an extent that little trouble is now encountered from the snow in the canals. The fences, trees, tall grass, and stubble all help to catch the drifting snow that would otherwise be lodged in the canals and ditches. Now that it is possible to run water into

reservoirs during the late fall and winter months, and there is more water at this season of the year to run, there is no lack of winter water to fill all the reservoirs at present constructed.

EXCHANGE OF WATER.

From the description of the reservoirs of the valley it will be seen that but few of them can be made to serve directly the lands of their owners. For the utilization of the others some system of exchange of water is necessary. The plan which has worked itself out, and has since been sanctioned by law, is the most important feature of reservoir development in Colorado. In consequence of the adoption of this system of exchange it matters little whether the reservoirs of a canal enterprise lie above or below its lands so long as its water can be traded off for an equal amount which can be taken into the head of the canal which covers all the land of the proprietors. The only thing to be considered is the ability to find someone who has something to give in exchange—either reservoir water or river water. The plan of exchange or "trading round" of water was conceived, agreed to, and carried on by the people themselves without legislative enactments, court decrees, or legal counsel or advice. It was simply the outcome of the necessity to dispose of water profitably that could not be utilized on lands in one locality by transferring it to another, thus benefiting one and often both of the parties to the exchange. It was first brought about by practical men, getting together in a friendly, neighborly, and businesslike manner, and consolidating the rights that each might have under existing laws into one common interest in the storage of water. The result has been that there has been no quarreling or litigation over the division and exchange of water from reservoirs.

It has been found necessary, however, to have a uniform method of determining quantities used in the exchange; also to have someone delegated to act as a sort of public gager, and in 1897 the following law was enacted at the instance of reservoir proprietors, legalizing the exchange and providing for measuring the water:

AN ACT to provide for and to regulate the exchange of water between reservoirs and ditches and the public streams.

SEC. 4. When the rights of others are not injured thereby, it shall be lawful for the owner of a reservoir to deliver stored water into a ditch entitled to water or into the public stream to supply appropriations from said stream, and take in exchange therefor from the public stream higher up an equal amount of water, less a reasonable deduction for loss, if any there be, to be determined by the State engineer: *Provided*, That the person or company desiring such exchange shall be required to construct and maintain under the direction of the State engineer, measuring flumes or weirs and self-registering devices at the point where the water is turned into the stream or ditch taking the same, or as near such point as is practicable, so that the water commissioner may readily determine and secure the just and equitable exchange of water as herein provided.

Most of the reservoirs had either measuring flumes or weirs at their outlets prior to the passage of this act, and it was quite an easy matter to determine the outflow when the depth of water was known. The instrument provided for by law records the depth of the water at all times. This, with the rating table, furnishes the data for accurately computing the discharge, no matter what may have been the fluctuations of the depth during the time the outlet gates were raised.

None of the reservoir companies have as yet complied with the requirement of the law concerning registering devices. They have got along so well and smoothly in the exchange of water, and up to this time have been able to divide it among themselves so satisfactorily to all with the crude apparatus they have, that they have not thought it worth while to provide for the more precise measurements, although there is a growing desire on the part of all to be sure that they give no more water than they get in exchange. It is quite probable that the law will be enforced in the near future, and it should be for the sake of the harmony that has so far existed among the reservoir proprietors. Guesswork or rough approximations are sure in time to lead to more or less dissatisfaction, especially when something else can be so easily substituted that shares the confidence of all.

In order to make clearer the possibilities of exchange under the law of 1897, the system adopted in this valley will be described somewhat in detail. For this purpose some of the facts stated in the description of the reservoirs are repeated here.

Beginning at the lower end of the valley and coming up the stream, the Greeley No. 3 Canal is the first one met with. It serves lands colored orange on the map (Plate XI). This canal has an early priority, but no reservoirs. Whatever reservoir water it uses must be obtained by exchange. The next canal is the Greeley No. 2, covering land colored green on the map. The farmers under this canal own the Cache la Poudre Reservoir, which is situated above their ditch, so that they can use their stored water directly. The Larimer and Weld Canal lies next above Canal No. 2, and covers the land colored blue on the map. The irrigators under this canal own two reservoirs—the Windsor, belonging to B. H. Eaton, who farms about 16,000 acres under this canal, and the Larimer and Weld Reservoir, belonging to a large number of farmers. The Windsor Reservoir lies below the canal and can serve the lands of its owner only through exchange. The Larimer and Weld Reservoir lies above the canal and can serve the lands of its owners directly. The next canal above is the Larimer County Ditch, which covers the land colored red on the map. The company owning the canal owns a series of reservoirs, all of which are below their ditch, and which can be utilized only by exchange. Lying above this canal is the North Poudre Ditch, with its system of reservoirs below the ditch, but so situated that a part of the water stored

MAP
OF A PORTION OF THE
CACHE LA POUDRE VALLEY
Showing the Exchange of Water
COLORADO

SCALE OF MILES
0 1 2 3 4 5

LEGEND
- Lands Under North Poudre Canal
- Lands Under Larimer County Canal
- Lands Under Larimer & Weld Canal
- Lands Under Cache la Poudre Canal No. 2
- Lands Under Union Colony Canal No. 3
- Artificial Water Channels
- Natural Water Channels

MAP SHOWING
CHAMBERS LAKE
AND HEAD WATERS OF THE
CACHE LA POUDRE
AND LARAMIE
RIVERS

R. 70 W. R. 69 W. R. 68 W. R. 67 W. R. 66 W. R. 65 W. R. 76 W. R. 75 W.

T. 10 N. T. 9 N. T. 8 N. T. 7 N. T. 6 N. T. 5 N. T. 3 N. T. 7 N.

North Fork Cache la Poudre River
Cache la Poudre River
Big Thompson River
South Platte River
LARIMER COUNTY
WELD COUNTY
NORTH POUDRE CANAL
NORTH POUDRE RESERVOIRS No. 1 No. 2 No. 3 No. 4 No. 5
ROCKY RIDGE RESERVOIR (No. 1)
BOX ELDER CREEK
PLEASANT VALLEY AND LAKE CANAL
CLAYMORE LAKE
TERRY LAKE
LONG POND
DRY CREEK
LARIMER COUNTY CANAL
LARIMER AND WELD CANAL
LARIMER COUNTY CANAL NO. 2
NEW MERCER DITCH
FORT COLLINS
CACHE LA POUDRE RESERVOIR
LAKE LEE
WINDSOR RESERVOIR
LONE TREE CREEK
EATON
FOSSIL CREEK RESERVOIRS
CACHE LA POUDRE CANAL NO. 2 OR GREELEY CANAL NO. 2
WINDSOR
LOUDEN DITCH
HORN CREEK
KILBURN LAKE
LOVELAND
LOVELAND AND GREELEY CANAL
UNION COLONY CANAL NO. 2
GREELEY
GREELEY CANAL NO. 3
EVANS
D. & C. LARAMIE RIVER
LARAMIE RIVER DITCH
WEST LARAMIE CANAL
LOST LAKE
LARAMIE LAKE
CHAMBERS LAKE ALTITUDE 9801 FT.
NORTH FORK CACHE LA POUDRE RIVER
MIDDLE FORK CACHE LA POUDRE RIVER
JOE WRIGHT CREEK
TRAP LAKE
TRAP CREEK

in them can be used on lands belonging to the ditch company, but only a part, and the rest must be exchanged. The lands covered by this canal are colored yellow on the map. The priorities of the ditches named are, in general, in the order in which they occur on the stream, coming up. This is not absolutely true of the lower three, as their construction and enlargements took place nearly at the same time, so that they each have several appropriations, with others intervening. The following table gives the dates and amounts of the appropriations of all the canals considered:

Appropriations from the Cache la Poudre River.

Canal.	Date of appropriation.	Decree.	Sum of appropriations.	Previous appropriations from the stream.
		Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*
Larimer and Weld	June 1, 1864	3	3	213.86
Larimer and Weld, first enlargement	Apr. 1, 1867	16.66	19.66	385.25
Mason and Hottel Mill	Apr. 15, 1867	60	60	401.91
Greeley No. 3	Apr. 1, 1870	52	52	692.77
Greeley No. 2	Oct. 25, 1870	111	110	759.19
Greeley No. 2, first enlargement	Sept. 15, 1871	170	280	1,158.01
Larimer and Weld, second enlargement	Sept. 20, 1871	75	94.66	1,328.01
Greeley No. 3:				
First enlargement	Oct. 1, 1871	41	93	1,403.01
Second enlargement	July 15, 1872	63.13	156.13	1,506.22
Third enlargement	May 15, 1873	16.67	172.80	2,043.17
Greeley No. 2, second enlargement	Nov. 10, 1874	184	464	2,229.70
Larimer and Weld, third enlargement	Jan. 15, 1875	54.33	148.99	2,413.70
Greeley No. 2, third enlargement	Sept. 15, 1877	121	585	2,498.50
Larimer and Weld, fourth enlargement	Aug. 1, 1878	571	719.99	2,653.79
Larimer County	Apr. 25, 1881	469.80	469.80	3,653.91
North Poudre Canal	(a)	315	315	4,123.71

a In 1893 the appropriation of this canal was adjudged to be junior to that of the Larimer County Canal.

The order of these priorities is very fortunate for the exchange of water, since the ditches which can from their location use the water from each reservoir have in every case the right to water ahead of the canal serving the lands of the owners of the reservoir, leaving out of account the two reservoirs which can be used directly. When the stage of the river is such that the Larimer and Weld Canal is entitled to nothing but its first two small appropriations amounting to 20 cubic feet per second, and the owner of the Windsor Reservoir must draw on his stored water, No 2 and No. 3 canals, the only ones which can take his reservoir water, still have a considerable quantity of water flowing to them, for which he can exchange. He opens his gates and runs water to these canals, and turns into the Larimer and Weld Canal from the river the water to which they are entitled. In this particular exchange there is a disturbing element which has not before been mentioned, the Mason and Hottel Mill appropriation. This mill is a flouring mill, usually driven by water power, but on account of seasons of low water and for other causes the proprietors have been obliged to introduce steam power, which can at any time be substituted in part or entirely for the water power. This has frequently

been done when the mill was short for water or when some irrigation interest above would furnish the fuel for the steam power in exchange for the 60 cubic feet of water per second required to drive the mill. The constitution of Colorado makes the use of water for mechanical purposes secondary to its use for domestic purposes and irrigation, but prior to the adoption of the constitution and before this distinction had been legally sanctioned, what is now known as the Mason and Hottel mill race and been constructed and diverted water from the river. The courts have placed this appropriation upon an equal footing with those made for irrigation, on the ground that the right had vested prior to the adoption of the constitution. This is one of the earliest rights on the river, and is prior to those of all the canals here discussed, except the first two small appropriations of the Larimer and Weld Canal. The head of this mill race is below the head gate of the Larimer and Weld Canal and the tailrace returns the water to the river above the head gates of the Greeley No. 2 and No. 3 canals, and the inlet ditch of the Cache la Poudre Reservoir. Therefore, although the mill does not consume the water, it prevents any canals but those heading below the tailrace using the 60 cubic feet per second which runs through its wheels. The mill uses the same water which goes to supply No. 2 and No. 3 canals, and they can not give it to anyone above the mill, unless the milling company be bought off. So that any exchange between No. 2 and No. 3 canals and the upper reservoirs must be with the consent of the milling company, unless there is more than 60 cubic feet per second flowing down to these canals. During the past summer, in order to get water to his lands under the Larimer and Weld Canal, B. H. Eaton has been obliged to furnish water from the Windsor Reservoir to No. 2 Canal, and also to furnish coal to the Mason and Hottel Mill. When he has done that he may divert the water belonging to No. 2 Canal at the head of the Larimer and Weld, and so take it to his lands. If his reservoir was so situated that he could return the water to the river above the mill race, all this trouble would be avoided, and he could then supply the mill and No. 2 Canal with the same water. The other reservoirs, higher up the stream, are so situated that their owners could return the stored water to the river above the mill race and so have an advantage in exchanges, and the plans of the Water Supply and Storage Company provide for an outlet ditch from their reservoir to the river for that purpose.

When the river has fallen so that the Larimer County ditch gets no water but what it turns into the stream in the mountains, and it must draw on its reservoirs, all the ditches below it are still entitled to water, and it has only to turn its water into the Larimer and Weld Canal or into the river above No. 2 and No. 3 canals and take as much from the river as it supplies to the other canals.

So with the North Poudre Canal. All the canals below it have rights

prior to its own and can supply it when its river supply is gone. This canal has this disadvantage, it heads in the North Fork of the river and can get no more water in exchange than is carried by that branch, no matter how much it can supply to the lower canals.

The transactions so far mentioned have only two parties. Much more complicated ones are sometimes made, including several or all of the canals in one exchange. The beginning of this exchange and its subsequent development are described in the following communication from R. Q. Tenney, of Fort Collins, who was the first person employed to superintend the division of water under the exchange system. Mr. Tenney was at that time water commissioner of District No. 3, which includes the country drained by the Cache la Poudre River, but he was not acting in an official capacity in this work. He was engaged by the reservoir people because of his acquaintance with the water and irrigation problems in the valley, also because they had confidence in his ability and integrity.

THE SYSTEM OF EXCHANGE IN THE POUDRE VALLEY.

The practical part of utilizing all the water of this district did not present itself to our people until they were face to face with the hard fact that what they had stored in the reservoirs that they had constructed was not available for their own use. In other words, what they had saved lay below the line of their own ditches, and consequently was not available for use on their own crops.

We sometimes run into a corner and find ourselves in a dilemma. This is just the fix we were in about 1893. Previous to this, however, and as early as 1885 or 1886, the Larimer County Ditch Company constructed a dam at the outlet of Chambers Lake, which is 42 miles west and 1 mile north of Fort Collins, for the purpose of storing water. The Larimer County ditch had the junior appropriation of any considerable amount in the district. It was evident from the inception of this enterprise that some provision must be made to augment the very uncertain supply that the ditch would receive. Chambers Lake seemed to be the only thing that presented, and it was seized upon and improved by that company. Water was stored here at different depths up to June 9, 1891, when the intake was in excess of the capacity of the discharge conduit, and the water rising to the top of the spillway, the dam, which was constructed of gravel, soon gave way, and we had quite a disaster. No lives were lost, but considerable property was destroyed. This disaster had the effect of stimulating the construction of more reservoirs and on a more substantial basis. From time to time the different large ditches began the construction of reservoirs that would, when filled, reenforce their supply, especially for late irrigation. The Windsor Reservoir was the first large undertaking It was constructed by ex-Governor B. H. Eaton. Water was drawn from it in 1892, before it was completed. At this time no system of exchange had been arranged, and the several million cubic feet stored in this reservoir were given to the No. 2 Greeley ditch, which runs immediately below.

The same year (1892) the Larimer County Ditch Company, now known as the Water Supply and Storage Company, had stored water in their Long Pond Reservoir to a depth of 17 feet. This was turned into the Larimer and Weld Canal and an equal quantity of water belonging to that canal was taken into the head of the Larimer County Ditch, which heads some 8 miles farther up the river. This would seem to be the first exchange of water between the several ditches and reservoirs. The owners of the Larimer and Weld Reservoir and the Cache la Poudre Reservoir

were fortunate in being able to discharge their stored water into their own ditches; therefore they did not figure in the exchange.

The season of 1893 was a short water season, and necessity for a careful conservation of all the water was early apparent. The right of Governor Eaton to store water being senior to all others, he had a large amount in reserve when the stream began to diminish. The question came up as to how this transfer and exchange should be controlled. At a meeting of representatives of all the interested parties, held at Eaton, it was decided that, as there was no legal provision to cover the case, it should be left in charge of the water commissioner of the district; that he should have entire supervision and keep an accurate account of the matter from first to last. The writer was then acting water commissioner of District No. 3. Here was a new problem to solve. All the conditions that would make an exchange just and accurate were lacking. The first move was to construct proper weirs for the measurement of the stored water, at the most available points in the discharge ditches of the reservoirs. In one case we were fortunate in having a fairly good place. This was at the outlet of Lindenmeier Lake, which was in a deep cut some 60 rods long and about 20 feet wide. Here we constructed a rectangular weir 12 feet wide and a drop about 4 feet. This set the water back to the discharge gate at the lake and gave us the nearest to perfect conditions of any weir in the district. The weir is standing to-day and has been used continuously since 1893. The amount discharged over this weir is as high as 150 cubic feet per second. This exchange was made between the Water Supply and Storage Company and No. 2 Greeley Ditch, the water being drawn from Long Pond through Lindenmeier Lake and discharged into the river above the head of No. 2. At the same time an equal amount was taken from the river by the Water Supply and Storage Company into their ditch, the head of which is located some 20 miles above the head of No. 2. By this method it will be seen that the Water Supply and Storage Company could benefit by the water they had stored and which lay below the line of their ditch.

In 1894 a new complication presented. The Windsor Reservoir Company wanted to exchange with the Water Supply and Storage Company. By reference to the map on page 38 it will be seen that the large ditches on the north side of the river have an elevation of about 200 feet each above the other, so that it was only a question of how the water could be conducted from one to the other. This necessitated the construction of ditches practically at right angles with the main lines. This had been done to a certain extent, but in order to exchange the amount that was desired these cross ditches had to be enlarged. This was not a difficult matter, because they all ran on a heavy grade and were cutting rapidly, and several drops had already become necessary. The outlet of Long Pond was about 90 feet above the Larimer and Weld Ditch and only about 80 rods distant. At this point a chute was contructed by nailing together 2 by 4's, making a flume about 6 feet wide, with sides about 2 feet high. In this chute, when it was carrying about 100 cubic feet per second, the water had a velocity of about 20 to 30 feet per second. This chute is constructed over the Larimer and Weld Ditch and Discharges into Lindenmeier Lake. (See Plate XII.) But in order to discharge into the Larimer and Weld Ditch a section of the bottom is detachable. The season of 1894 demanded another exchange, making three parties to participate at the same time. The Water Supply and Storage Company discharged into the Larimer and Weld; the Windsor Reservoir discharged into the No. 2, and the Water Supply and Storage Company took the same amount from the river, which would otherwise run down to No. 2. Here, then, were two parties benefiting by their stored water that lay below their own ditch.

This season (1900) has brought a new canal into the exchange. This is the North Poudre Canal. The appropriation of this company from the river is junior to all others, and it has a greater storage capacity than any other system. It has partially constructed this season (and used to the extent of several million feet) two reser-

FLUME OVER LARIMER AND WELD CANAL, CARRYING WATER FROM LONG POND.

voirs that, when completed, will store about a billion cubic feet. This company can discharge their stored water into the ditch of the Water Supply and Storage Company; they in turn can discharge into the Larimer and Weld, and they into No. 2, and the North Poudre Company can take into the head of their ditch, which is about 40 miles above No. 2, the same amount from the river.

Legislation became necessary to control the exchange of stored water, from the fact that it was not, under the old law, compulsory on the district commissioner to attend to it.

Within the past four years great progress has and still is being made in the matter of constructing storage reservoirs and the equitable exchange of water. From 20 to 30 per cent of increase in the irrigated area and an equal percentage of increase in the money value of the crops has been secured. The possibilities in this direction may be guessed at, but no one can say with any degree of certainty just what we can accomplish in another decade.

Fort Collins, Colo., ———, 1900.

THE VALUE OF RESERVOIRS.

It has already been suggested that the present advanced stage of agriculture in the Cache la Poudre Valley was made possible by the construction of the storage reservoirs which have been described. The water stored is not saved by scrimping in one period for use in another; it is saved from waste and is therefore an addition to the available supply. Before the day of reservoirs, crops often failed for lack of water; the increased supply has made possible a good crop every year. But the most noticeable effect of storage is the farming of higher-priced crops than could be raised before. Potatoes, for instance, could be raised only by those having early priorities, and this would limit their culture to a very small area. Now potatoes are one of the leading crops of the valley, and depends almost wholly upon stored water. We are indebted to the manager of the Greeley Mercantile Company for the following estimate of the increase in the value of the potato crop for the past four years, due solely to the supply of late water from reservoirs. Mr. Watson gives the number of carloads shipped, the average price per carload, and estimates the portion of each crop which may properly be credited to the use of reservoir water. The prices given are those received by the farmers for potatoes in carload lots.

Value of potato crop in Cache la Poudre Valley, 1897–1900.

Year.	Carloads.	Value per carload.	Value of crop.	Portion of the crop due to reservoir water.	Value of crop due to reservoir water.	Remarks.
1897	7,000	$200	$1,400,000	Two-thirds	$933,333	Good crops, fair price, large acreage, but short water in river.
1898	5,500	175	962,500	One-half	481,250	Normal flow of water in river.
1899	4,500	175	787,500	All	787,500	No water in river for potatoes.
1900	*a* 4,100	210	361,000	All	861,000	Do.
Total	21,100		4,011,000		3,063,083	

a Estimated.

The 21,100 carloads do not represent all the potatoes raised in the valley during these four years. It is estimated that one-eighth of the total product is not marketed in carload lots, and consequently is not included in the table. This represents home consumption and unmarketable potatoes. Letting these offset the additional expense of raising and harvesting a full crop rather than a half crop or no crop, we may fairly count the increase shown in the table as a net profit due to the use of reservoir water. The cost of the reservoirs has been given as $344,600. The figures in the table show, then, for the four years, an annual profit of 222 per cent. This, however, is not a fair statement of the case. If there were no reservoirs the land would not have been planted to potatoes, and would probably have produced a good crop of grain or two crops of alfalfa, as these can almost always be matured with the natural flow of the river. What should be considered in estimating the value of reservoir water is the difference between the value of the crops matured with stored water and the value of the crops which could have been raised without it. This, from the nature of the case, can not be definitely estimated. The Yearbook of the United States Department of Agriculture for 1899 gave the average return per acre for potatoes, in Colorado, as $46.20, and the average for wheat, $13.51. This would show an increased value of $32.69 per acre. The expense of harvesting potatoes is considerably greater than that for harvesting grain, so that this is not a net gain, but there is no question that potatoes are the more profitable crop. And there is no question among reservoir stockholders about this increase being sufficient to make the reservoirs a paying investment. However, exact figures in the matter are impossible.

As has been stated before, the use of reservoirs makes sure a third crop of alfalfa, which could seldom be obtained without them. No estimates have been made of the value of this third crop of alfalfa. This crop is not usually marketed, but is fed to sheep at home. Pl. XIII shows in a small way the method of feeding and fattening sheep. The sheep are not raised in the valley but are purchased each fall, fed through the winter, and marketed in the spring. They are fed from about November 1 to May 15, and during this time will consume about 400 pounds of hay per head. They are also fed some corn. It is estimated that about 500,000 head will be fed in the Cache la Poudre Valley during the season of 1900–1901. This means that 200,000 tons of alfalfa will be required—approximately the yield of 50,000 acres of land. Probably one-fourth to one-fifth of this alfalfa is raised with late water.

But the value of these reservoirs to the agricultural interests of the valley can not be measured by the money returns from the crops matured by the use of stored water. It has been shown that the use of the reservoirs has been greatly extended by the system of exchange.

SHEEP-FEEDING PENS.

It has done away with the necessity of building long outlet canals for utilizing stored water and has probably led to the improvement of sites which would still be unused but for this method of disposing of water. But it has had a far better result. It has shown the farmers and canal companies the fallacy of the cut-throat policy which they have followed for years, and has begotton a spirit of cooperation which, if carried over into the management of their canals, will increase the efficiency of their water supply far more than has been done thus far by the storage of the water which ran to waste during the winter and flood period. To do this would require a partial waiving of the rights to divert the quantity of water decreed them under any and all conditions heretofore asserted by most appropriators. This would result in injury to no one if properly carried out; on the other hand, it would be a benefit to a large majority of the water users in the valley. Experience has proven that rotating in the use of water from canals results in a great saving both of time and of water. Every practical irrigator realizes the advantage of having a large head of water for a short time rather than a small head for a long time. Much more can be accomplished with 10 cubic feet per second for one day than with 1 cubic foot per second for ten days. No sane man would undertake to irrigate his 160-acre farm all at one time when he has only water enough to flow over 10 acres. He would "bunch" his water instead of scattering it all over his farm through so many channels that more than half the water would be absorbed in wetting the ditches. If the distribution of water in the river and in the canals in times of scarcity was managed with the same economy as is practiced by the individual irrigator it would add millions to the value of the products of the valley.

It is a notorious fact that many of the smaller ditches were given decrees to more water than they can carry and that they divert more than the land covered needs, for the sole purpose of keeping some one else from getting title to the use of that water. The larger ditches divert all the water they can get, for the same reason. A pooling of all the rights to the stream would do away with this dog-in-the-manger policy, and all the water wasted in this way could be saved and applied to a beneficial use, because no one would be afraid of losing his title if he failed to run his ditch full whether he needed it or not.

But some one will ask, What about prior rights? It is not too much to predict that in the near future prior rights will be lost sight of as the mutual advantages to all in the most economical management of the water supply is recognized and the rights to water are construed, as they should be, as rights to make a beneficial use of it, not to waste it. The tendency seems to be toward such cooperation, and it needs no prophetic vision to see in the future a cessation of litigation and strife, and greatly extended cultivation by the use of the

water made available by uniting all the interests in the stream. This spirit of cooperation was born of the necessity of mutual accommodation in the operation of reservoirs, and its results may fairly be considered in part due to their construction.

THE DISCHARGE OF THE CACHE LA POUDRE RIVER AND THE RIGHTS TO ITS WATERS.

The rights to the water from the Cache la Poudre River were adjudicated in 1882, since which time no canals of any size have been begun. The sum of all the appropriations, as shown by the decree rendered at that time, is 4,442.73 cubic feet per second.[1] These appropriations are for direct irrigation, but they affect the operation of reservoirs, for the reason that water can be appropriated for storage only when there is a surplus in the stream not needed for direct irrigation, and canals with late rights to the river must store water or go without. The decrees aggregate much more than the average flow of the stream. In fact, there have been but two years since records have been kept in which the flood discharge reached for a single day the height necessary to fill these decrees. The diagrams (Pl. XIV, figs. 1, 2, 3) have been prepared to show graphically at what stage in the river the canals discussed in the preceding pages are entitled to water, and the times at which they would have received water if all the canals recognized in the decree diverted continuously the quantities decreed them. The heavy vertical lines show the average flow of the river in cubic feet per second for the times indicated at the heads of the columns. The tinted portions show the quantities decreed the canals indicated, and the parts not tinted represent in the same way the decrees of the canals not named in the diagrams. The scale at the right shows both the discharge of the river, as represented by the heavy vertical lines, and the stage of the river at which the various canals named are entitled to water under their decrees. For example: The Larimer and Weld Canal has, under its priority No. 79, a right to divert 571 cubic feet of water per second. The space tinted blue, about the middle of the diagram, marked "79 Larimer and Weld 571.00," represents this decree of the Larimer and Weld Canal. The position of this space on the diagram shows that before the canal is entitled to this water decrees for some 2,654 cubic feet of water per second must be satisfied. Fig. 3 shows that in the average year the canal would get no water under this decree, since the vertical lines representing the flow of the stream do not at any place reach the tinted space representing the decree. Like facts regarding any other decree can be found from the diagram.

Pl. XIV, fig. 1, shows the discharge of the river during the season

[1] State Engineer's Report, 1883–84, Appendix, p. 13.

PLATE XIV.

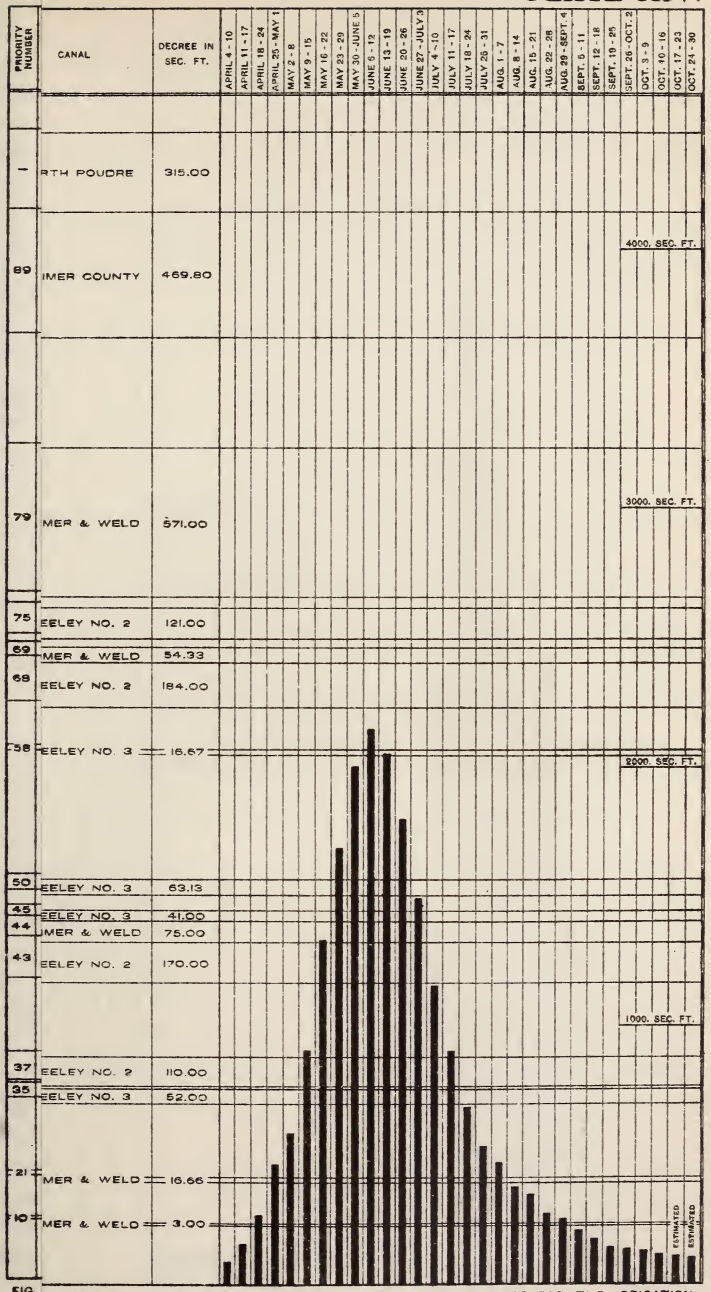


FIG. DIAGRAM SHOWING THE FLOW OF THE CACHE LA POUDRE RIVER FOR THE IRRIGATION SEASONS 1884-1899 AND THE STAGE AT WHICH CERTAIN CANALS ARE ENTITLED TO WATER.

PRIORITY NUMBER	CANAL	DECREE IN SEC. FT.
—	NORTH POUDRE	315.00
89	LARIMER COUNTY	468.80
79	LARIMER & WELO	571.00
75	GREELEY NO. 2	121.00
69	LARIMER & WELD	
68	GREELEY NO. 2	184.00
58	GREELEY NO. 3	16.67
50	GREELEY NO. 3	63.13
45	GREELEY NO. 3	41.00
44	LARIMER & WELO	75.00
43	GREELEY NO. 2	170.00
37	GREELEY NO. 2	110.00
35	GREELEY NO. 3	
21	LARIMER & WELO	16.66
10	LARIMER & WELD	3.00

APRIL 4 - 10 · APRIL 11 - 17 · APRIL 18 - 24 · APRIL 25 - MAY 1 · MAY 2 - 8 · MAY 9 - 15 · MAY 16 - 22 · MAY 23 - 29 · MAY 30 - JUNE 5 · JUNE 6 - 12 · JUNE 13 - 19 · JUNE 20 - 26 · JUNE 27 - JULY 3 · JULY 4 - 10 · JULY 11 - 17 · JULY 18 - 24 · JULY 25 - 31 · AUG. 1 - 7 · AUG. 8 - 14 · AUG. 15 - 21 · AUG. 22 - 28 · AUG. 29 - SEPT. 4 · SEPT. 5 - 11 · SEPT. 12 - 18 · SEPT. 19 - 25 · SEPT. 26 - OCT. 2 · OCT. 3 - 9 · OCT. 10 - 16 · OCT. 17 - 23 · OCT. 24 - 30

4000. SEC. FT. · 3000. SEC. FT. · 2000. SEC. FT. · 1000. SEC. FT. · ESTIMATED · ESTIMATED

FIG. 1.—DIAGRAM SHOWING THE FLOW OF THE CACHE LA POUDRE RIVER FOR THE IRRIGATION SEASON OF 1889 AND THE STAGE AT WHICH CERTAIN CANALS ARE ENTITLED TO WATER.

PRIORITY NUMBER	CANAL	DECREE IN SEC. FT.
—	NORTH POUDRE	315.00
89	LARIMER COUNTY	469.80
79	LARIMER & WELO	571.00
75	GREELEY NO. 2	121.00
69	LARIMER & WELO	54.33
68	GREELEY NO. 2	184.00
58	GREELEY NO. 3	16.67
50	GREELEY NO. 3	63.13
45	GREELEY NO. 3	41.00
44	LARIMER & WELO	75.00
43	GREELEY NO. 2	170.00
37	GREELEY NO. 2	110.00
35	GREELEY NO. 3	52.00
21	LARIMER & WELO	16.66
10	LARIMER & WELO	3.00

APRIL 4 - 10 · APRIL 11 - 17 · APRIL 18 - 24 · APRIL 25 - MAY 1 · MAY 2 - 8 · MAY 9 - 15 · MAY 16 - 22 · MAY 23 - 29 · MAY 30 - JUNE 5 · JUNE 6 - 12 · JUNE 13 - 19 · JUNE 20 - 26 · JUNE 27 - JULY 3 · JULY 4 - 10 · JULY 11 - 17 · JULY 18 - 24 · JULY 25 - 31 · AUG. 1 - 7 · AUG. 8 - 14 · AUG. 15 - 21 · AUG. 22 - 28 · AUG. 29 - SEPT. 4 · SEPT. 5 - 11 · SEPT. 12 - 18 · SEPT. 19 - 25 · SEPT. 26 - OCT. 2 · OCT. 3 - 9 · OCT. 10 - 16 · OCT. 17 - 23 · OCT. 24 - 30

4000. SEC. FT. · 3000. SEC. FT. · 2000. SEC. FT. · 1000. SEC. FT. · ESTIMATED · ESTIMATED

FIG. 2.—DIAGRAM SHOWING THE FLOW OF THE CACHE LA POUDRE RIVER FOR THE IRRIGATION SEASON OF 1900 AND THE STAGE AT WHICH CERTAIN CANALS ARE ENTITLED TO WATER.

PRIORITY NUMBER	CANAL	DECREE IN SEC. FT.
—	NORTH POUDRE	315.00
89	LARIMER COUNTY	469.80
79	LARIMER & WELO	571.00
75	GREELEY NO. 2	121.00
69	LARIMER & WELO	54.33
68	GREELEY NO. 2	184.00
58	GREELEY NO. 3	16.67
50	GREELEY NO. 3	63.13
45	GREELEY NO. 3	41.00
44	LARIMER & WELO	75.00
43	GREELEY NO. 2	170.00
37	GREELEY NO. 2	110.00
35	GREELEY NO. 3	52.00
21	LARIMER & WELO	16.66
10	LARIMER & WELO	3.00

APRIL 4 - 10 · APRIL 11 - 17 · APRIL 18 - 24 · APRIL 25 - MAY 1 · MAY 2 - 8 · MAY 9 - 15 · MAY 16 - 22 · MAY 23 - 29 · MAY 30 - JUNE 5 · JUNE 6 - 12 · JUNE 13 - 19 · JUNE 20 - 26 · JUNE 27 - JULY 3 · JULY 4 - 10 · JULY 11 - 17 · JULY 18 - 24 · JULY 25 - 31 · AUG. 1 - 7 · AUG. 8 - 14 · AUG. 15 - 21 · AUG. 22 - 28 · AUG. 29 - SEPT. 4 · SEPT. 5 - 11 · SEPT. 12 - 18 · SEPT. 19 - 25 · SEPT. 26 - OCT. 2 · OCT. 3 - 9 · OCT. 10 - 16 · OCT. 17 - 23 · OCT. 24 - 30

4000. SEC. FT. · 3000. SEC. FT. · 2000. SEC. FT. · 1000. SEC. FT. · ESTIMATED · ESTIMATED

FIG. 3.—DIAGRAM SHOWING THE FLOW OF THE CACHE LA POUDRE RIVER FOR THE IRRIGATION SEASONS 1884-1899 AND THE STAGE AT WHICH CERTAIN CANALS ARE ENTITLED TO WATER.

of 1889. Less water passed the gaging station in that season than in any other since measurements have been made. The total discharge of the river for this season, from April 1 to October 31, is 184,738 acre-feet, or enough to cover 140,000 acres to a depth of 1.32 feet. If this was distributed through the season as needed it would be nearly sufficient to raise crops, provided little was lost or wasted in transportation.

Pl. XIV, fig. 2, shows the discharge for the season of 1900. The discharge of the river during this season was apparently larger than that of any season since the settlement of the valley, but the records do not show this. The rain and snow fall was unusually heavy in the spring, and much of this reached the river below the gaging station and does not show in the records. This probably accounts for the discrepancy between the apparent discharge and the records. It is estimated that during the month of May and the first half of June there was no time when the water left in the river, after the canals had diverted all they wanted, would not have filled all the constructed reservoirs in the valley in a few days. Yet the diagram shows that at no time during the season would the flow of the river fill the decrees, and for eight weeks only would it have filled the decrees of the canals named in the diagram, which always take all the water they can get, even if all the other canals took nothing from the river. The total discharge for the season is approximately 465,000 acre feet, or enough to cover 140,000 acres 3.32 feet deep.

Pl. XIV, fig. 3, shows the mean of all the measurements made of the discharge of the river. This diagram indicates that in the average year two of the five large canals are entitled to no water, while two more get very little, and that there is, therefore, no water for storage. This, of course, is on the supposition previously made, that all the canals continuously divert the full quantities decreed them up to the limit of the supply. The supposition made is not, however, borne out by the facts. Many of the small canals have decrees for more water than they can carry, and others for more than they can use beneficially, while most of the early canals were built to water bottom land, much of which has since become so wet from seepage that it needs draining rather than irrigating. The water not used by these early canals remains in the stream to satisfy later decrees, so that for a considerable part of most seasons all the canals in the valley take all the water they want. The failure of the diagram to show this is due to the lack of any means to express numerically the quantity which can be put to a beneficial use. There is no doubt that if decrees were rendered giving the right not to a fixed quantity, but to the quantity which could be put to a beneficial use upon specified areas of land, not to exceed a fixed quantity, a diagram representing the average flow of the river would show sufficient water to supply all the canals

now diverting water from the Cache la Poudre for the early part of the season. The average annual discharge of the river for the past fifteen irrigating seasons is approximately 290,000 acre-feet. A fair estimate of the area actually watered each year is 140,000 acres. The water flowing past the gaging station would cover this area to a depth of a little more than 2 feet, making no allowances for losses from evaporation or seepage in transportation. This depth of water would seem to be ample, even under the present irrigation practice. The diagrams show, however, that the distribution of this water throughout the season is not suited to the present system of agriculture. There is a surplus in early summer and a shortage later, making storage necessary for the best utilization of the total flow of the river.

Up to the present time the reservoirs have been almost wholly filled from the winter flow of the river, so that the water stored has been an addition to the supply available for use during the irrigating season. As shown in the tables given before, the quantity of water thus made available is now about 69,000 acre-feet, or more than one-fourth of the average flow of the river during the seven months of the legal irrigating season. This leaves the surplus water of the flood period still open to appropriation for storage. Nothing can be learned as to the amount of this surplus from the discharge records, for the reasons already stated; the decrees so far exceed the flow of the stream, and there is no means of telling how much water will be demanded under the decrees.

CONCLUSIONS.

(1) Reservoirs in the Cache la Poudre Valley are a paying investment.

(2) Storage of water in this valley is capable of extension.

(3) There is a necessity for increasing the carrying capacity of reservoir feeders.

(4) Reservoir embankments should be better protected from damage by wave action.

(5) Reservoir outlets should be inspected annually.

(6) Exchange of water facilitates its distribution and amplifies its use.

(7) Accurate measurement is essential in the exchange of water.

(8) The concert of action in the exchange of water appears to have lessened the number of legal conflicts.

(9) Laws based on the outcome of customs are usually well founded.

(10) Greater economy in the application of water is attained by alternating rather than prorating in times of scarcity, both among canals and among users from canals.

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